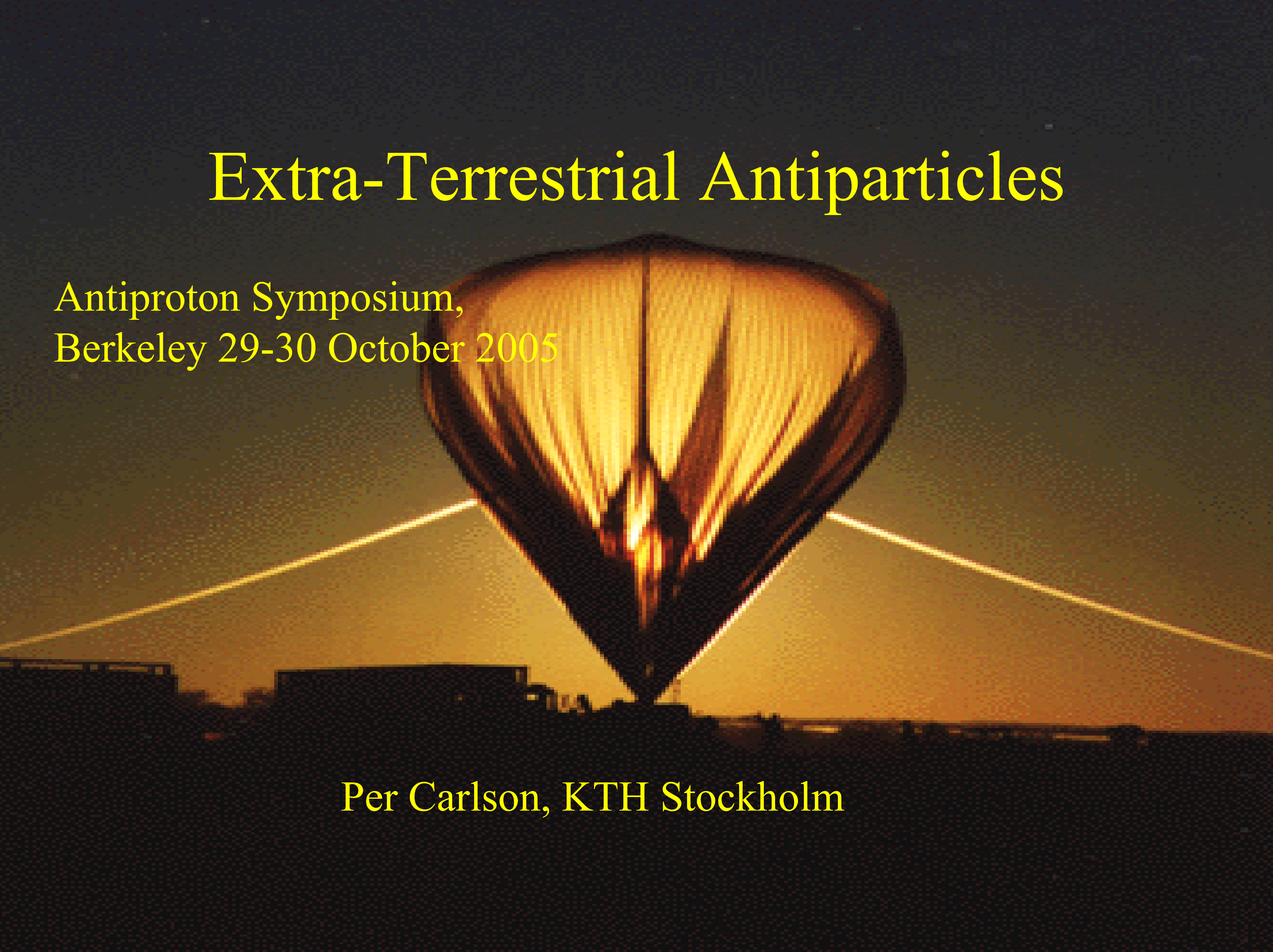
Extra-Terrestrial Antiparticles



Antiproton Symposium,
Berkeley 29-30 October 2005

Per Carlson, KTH Stockholm

Extra-terrestrial Antimatter

- The start
- Instrumentation that made it possible
- Science with antimatter
- Future experiments
- Conclusion

- *Dirac* suggested that there may be *antiworlds (ca 1930)*. The word *antiparticle* first used by de Broglie 1934

- Antimatter in cosmic-rays discussed by Bhowmik 1952 and by Fradkin 1954

- Alfvén discussed 1965 how matter and antimatter regions could be separated

- Balloon experiments to hunt for *cosmic antimatter* started after the discovery of the antiproton in 1955. Satellite experiments are ready for launch 50 years later

Background to fight:

- protons/positrons $\approx 10^3 - 10^4$
- In atmosphere (balloons) antiprotons must be distinguished from pions, muons, electrons. Background/signal $\approx 10^3$
- In space (satellites) electrons/antiprotons $\approx 10^2 - 10^3$
- For antinuclei scatterings are the most important background

The key to success: Particle identification

- *charge, momentum*: magnet and tracking

  spark chambers, MWPC, DC, Silicon

- *mass*: time-of-flight (ToF)

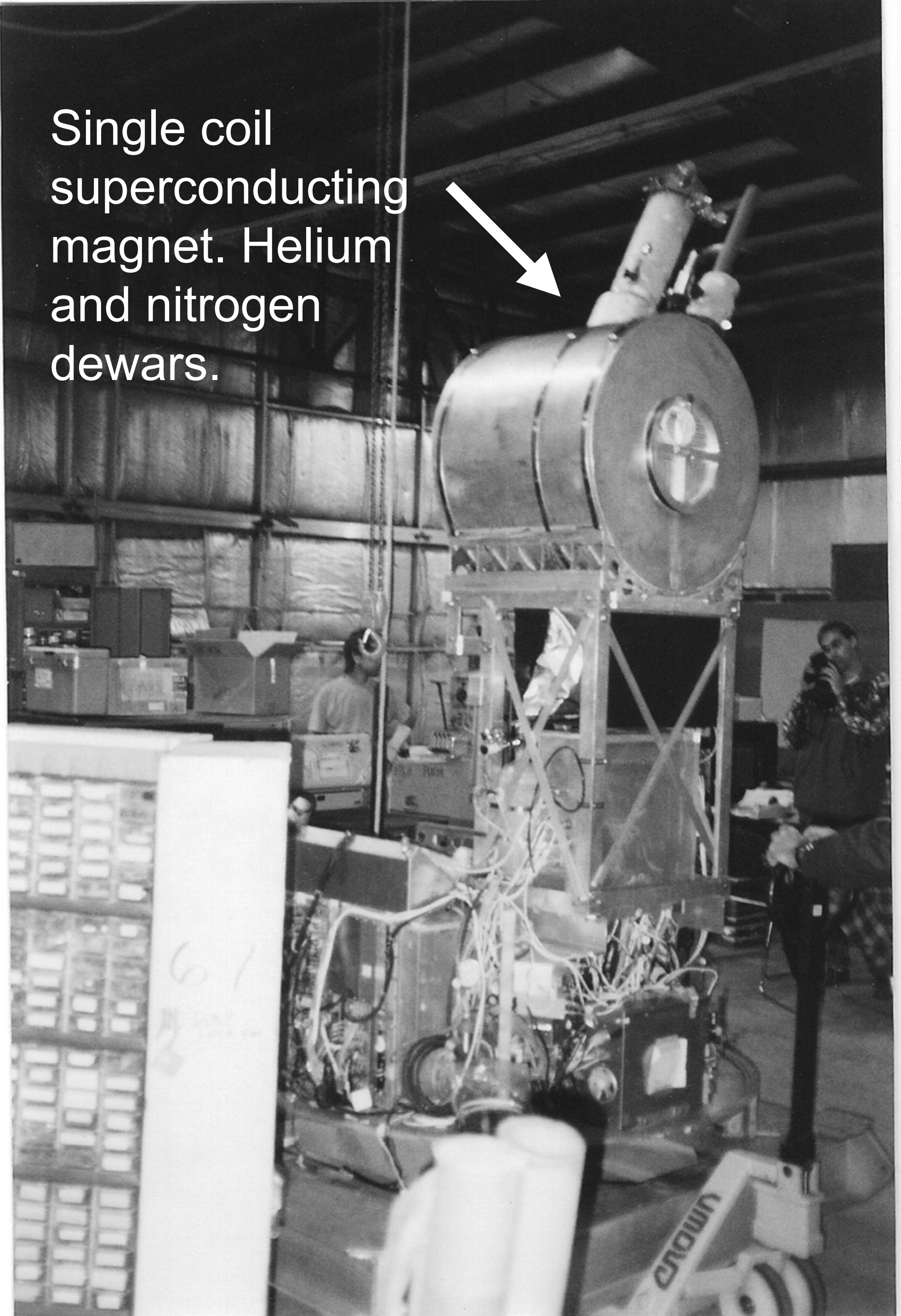
  dE/dx

  Cherenkov, in particular RICH

  calorimeter

Balloons and payloads were smaller in the beginning


CAPRICE98 launch



Bob Golden’s single coil superconducting magnet was flown 15 times from 1976 to 1998.

Easy to operate, but very inhomogeneous field.

Diameter: 36 cm – 61 cm

Life time: 100 h

Current: 120 A

Field max.: 4 T

Photo: S. Stochaj, NMSU

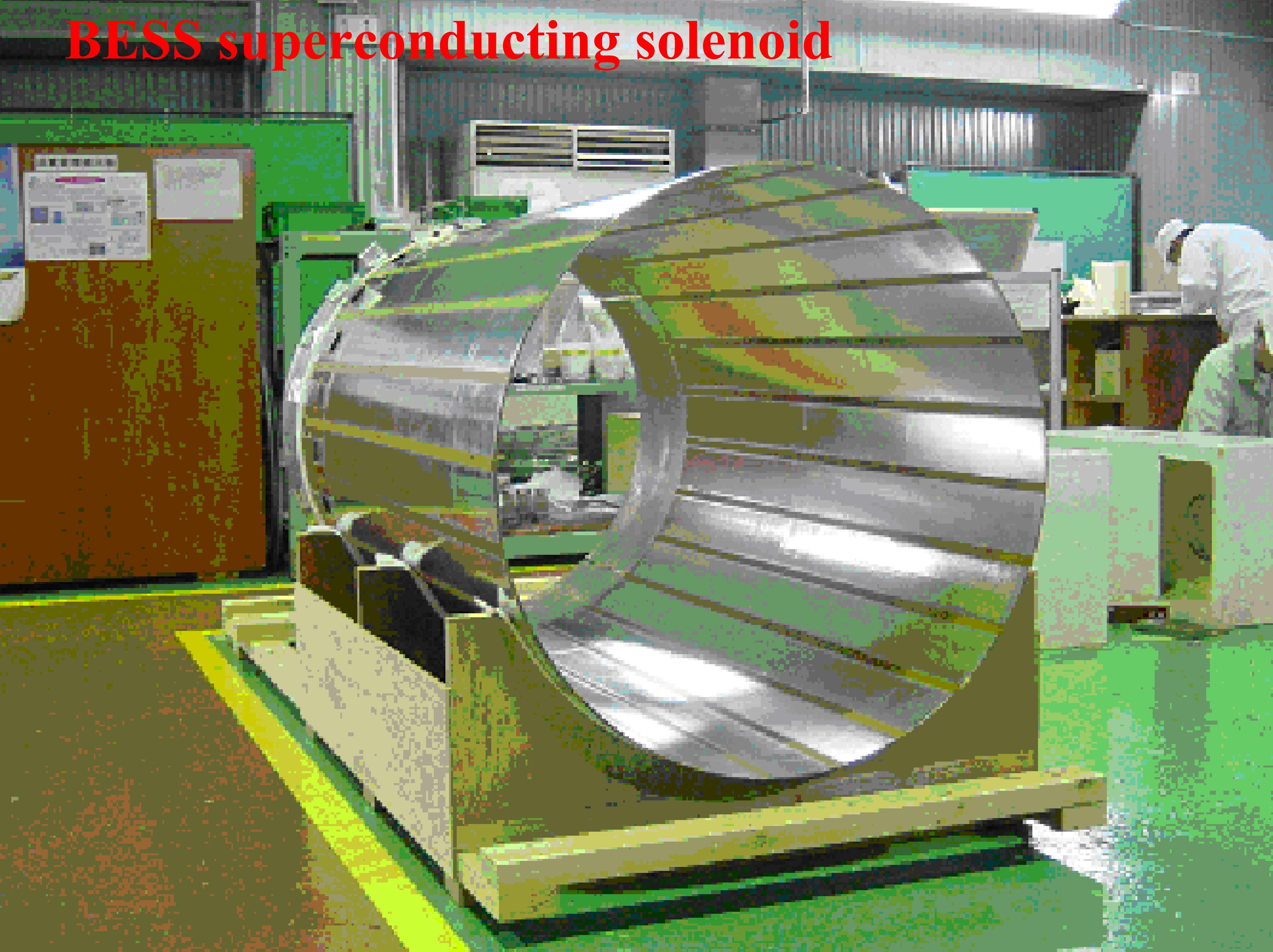
Photo PC

Bob Golden was given the <u>*Distinguished Public Service Medal*</u> on 24 February 1995

"For discovering antiprotons in cosmic rays and leading the development of superconducting magnet spectrometers for space-based and balloon-borne investigations of the cosmic radiation"

Bob with Vernon Jones, NASA at NMSU 24 February 1995. Bob made his PhD at UCB under L. Alvarez.

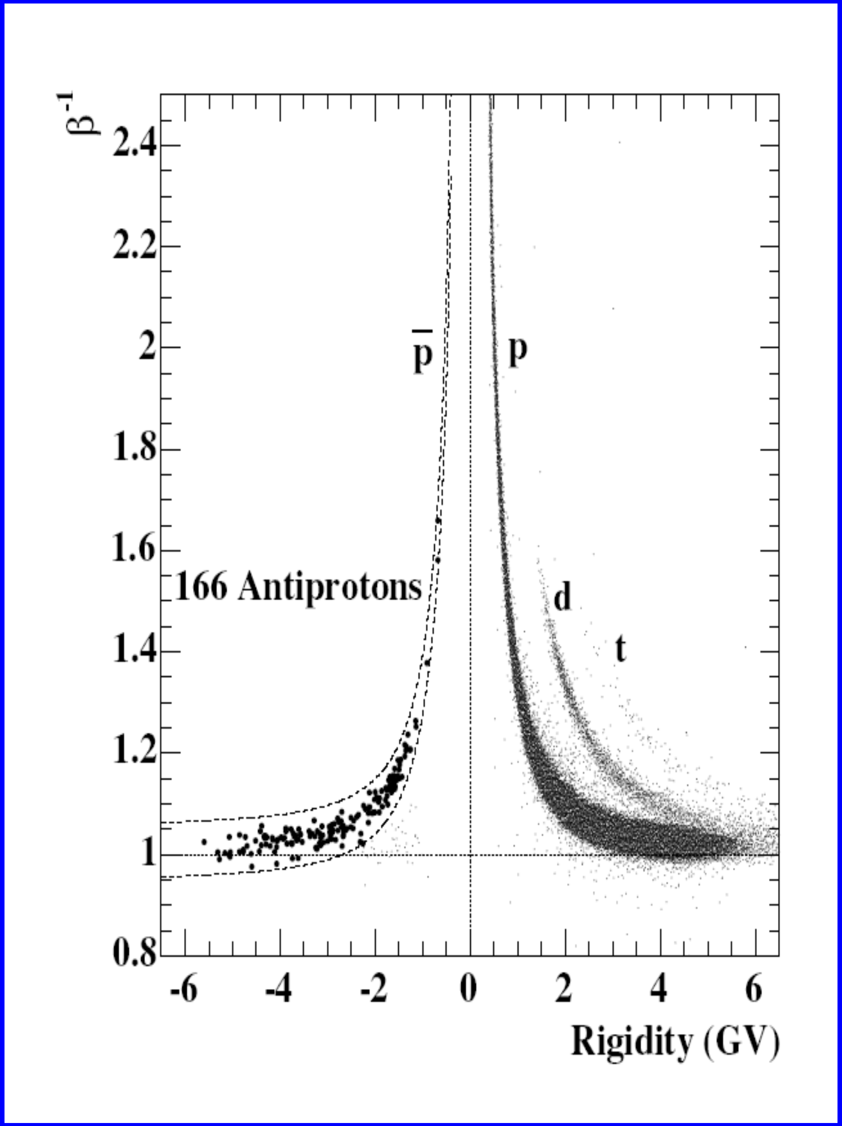
BESS superconducting solenoid



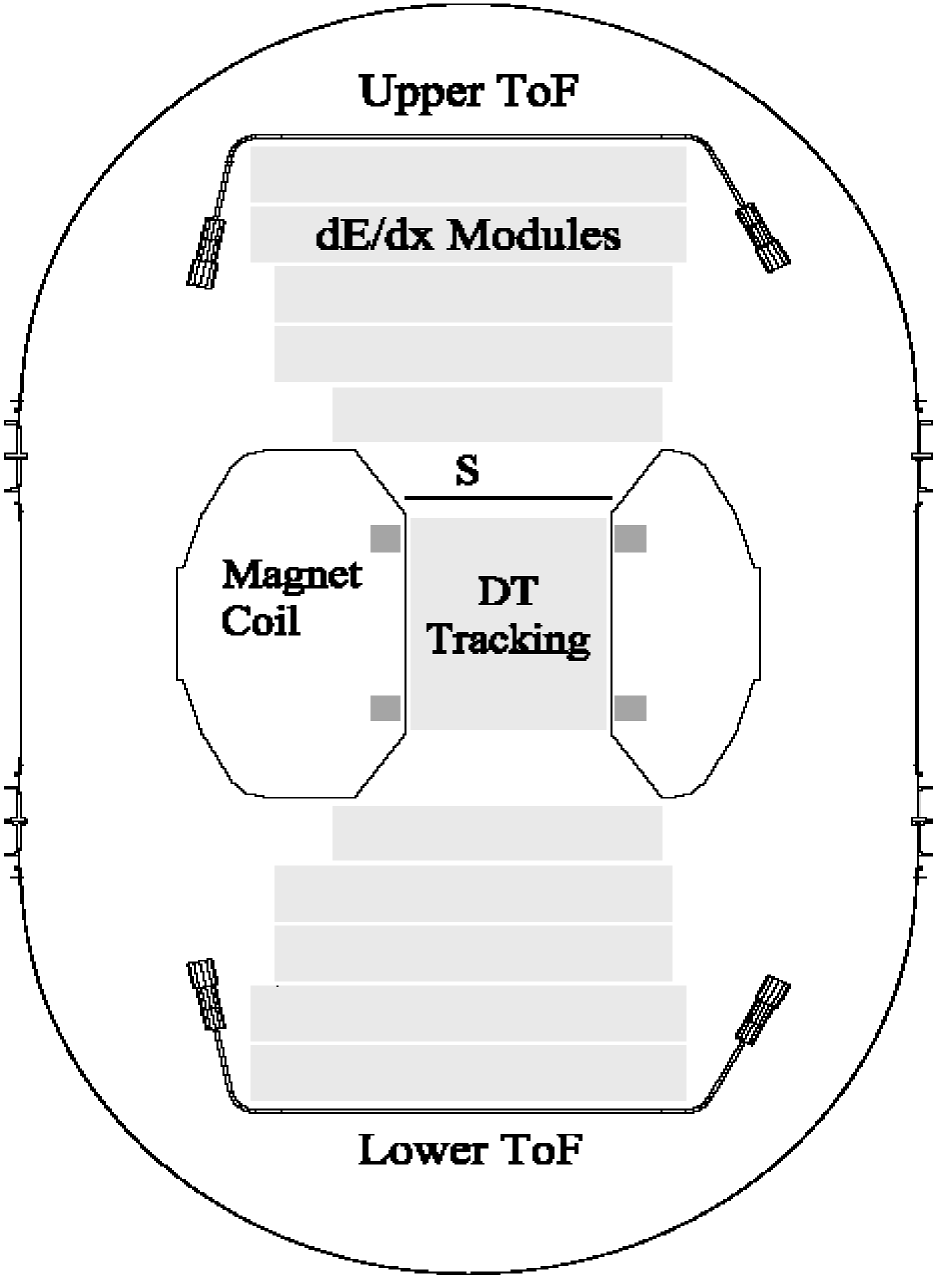
BESS 98 at the South Pole

BESS home page

BESS time-of-flight



S. Haino 29th International Cosmic Ray Conference Pune (2005)

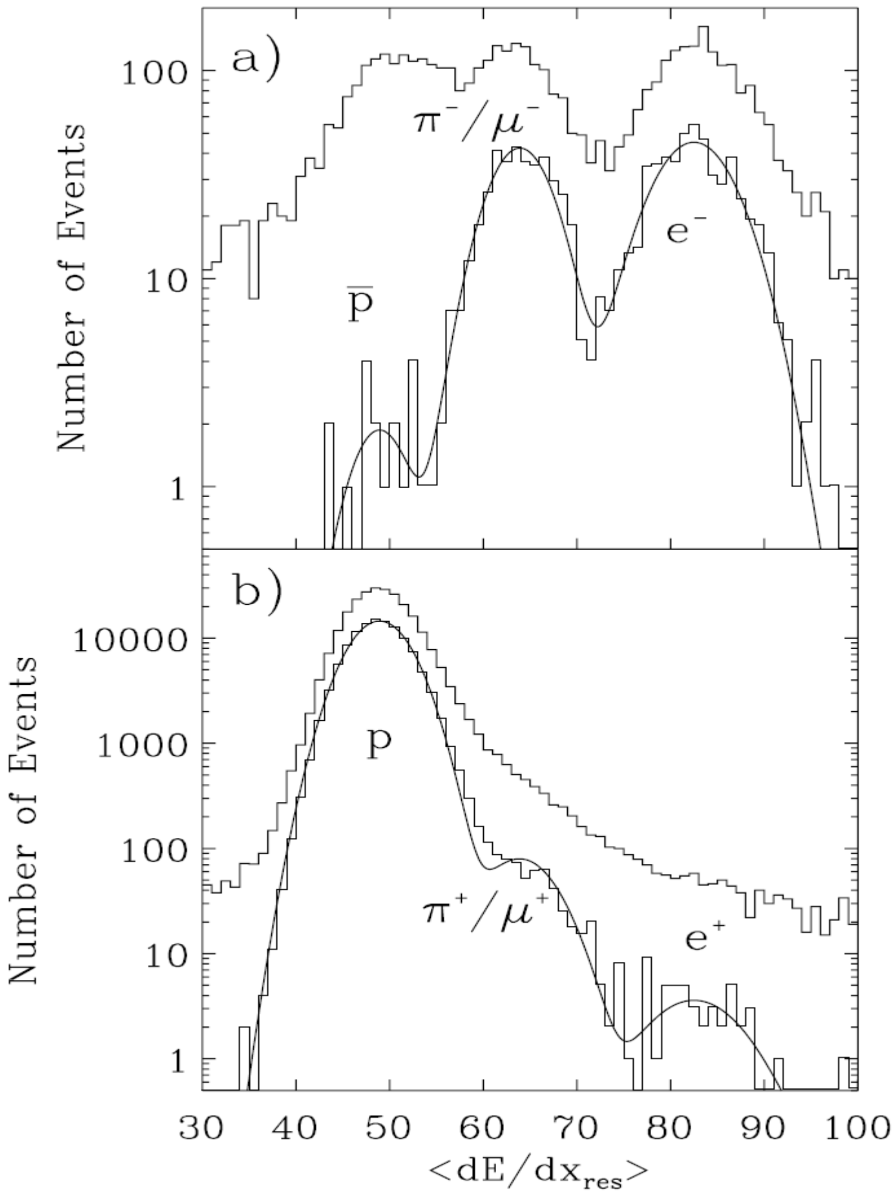


The HEAT experiment.

Particle ID by dE/dx measurements.

Height 2.8 m.

A.S. Beach et al. Phys. Rev. Lett. 87(2001)27110



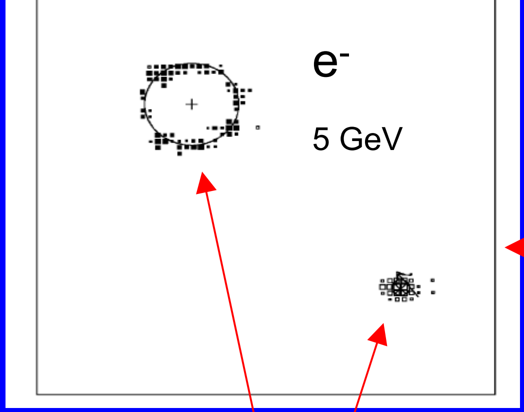
Example of background to fight in balloon experiments.

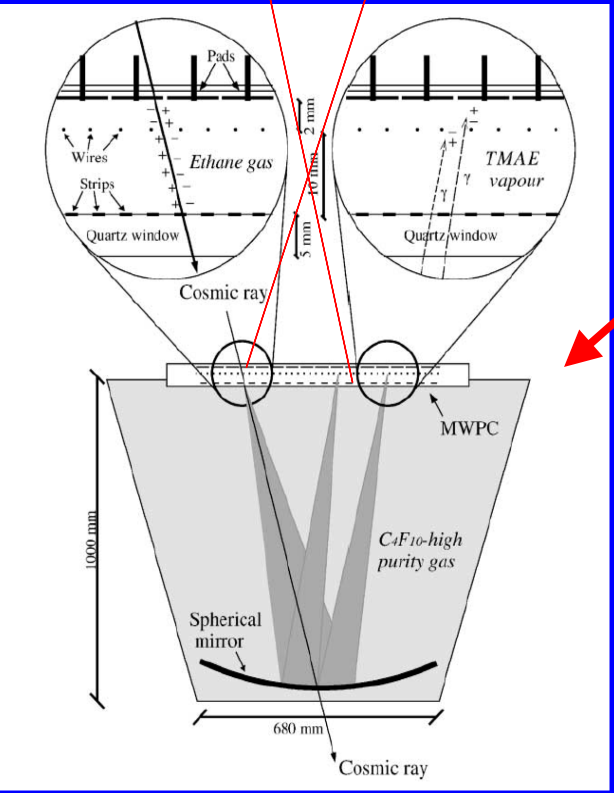
From the HEAT experiment.

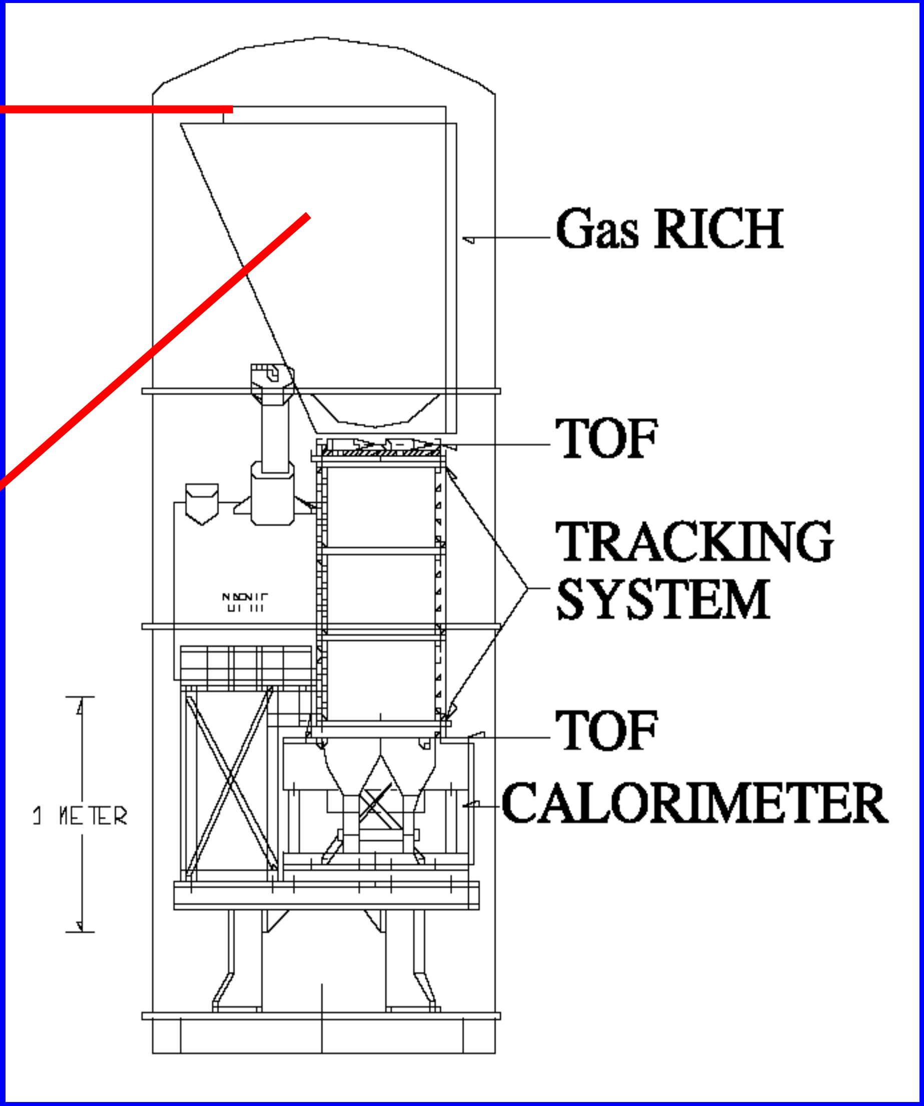
Data in the range 4.5 – 6 GV/c, before and after event selections.

A.S. Beach et al. Phys. Rev. Lett. 87(2001)27110

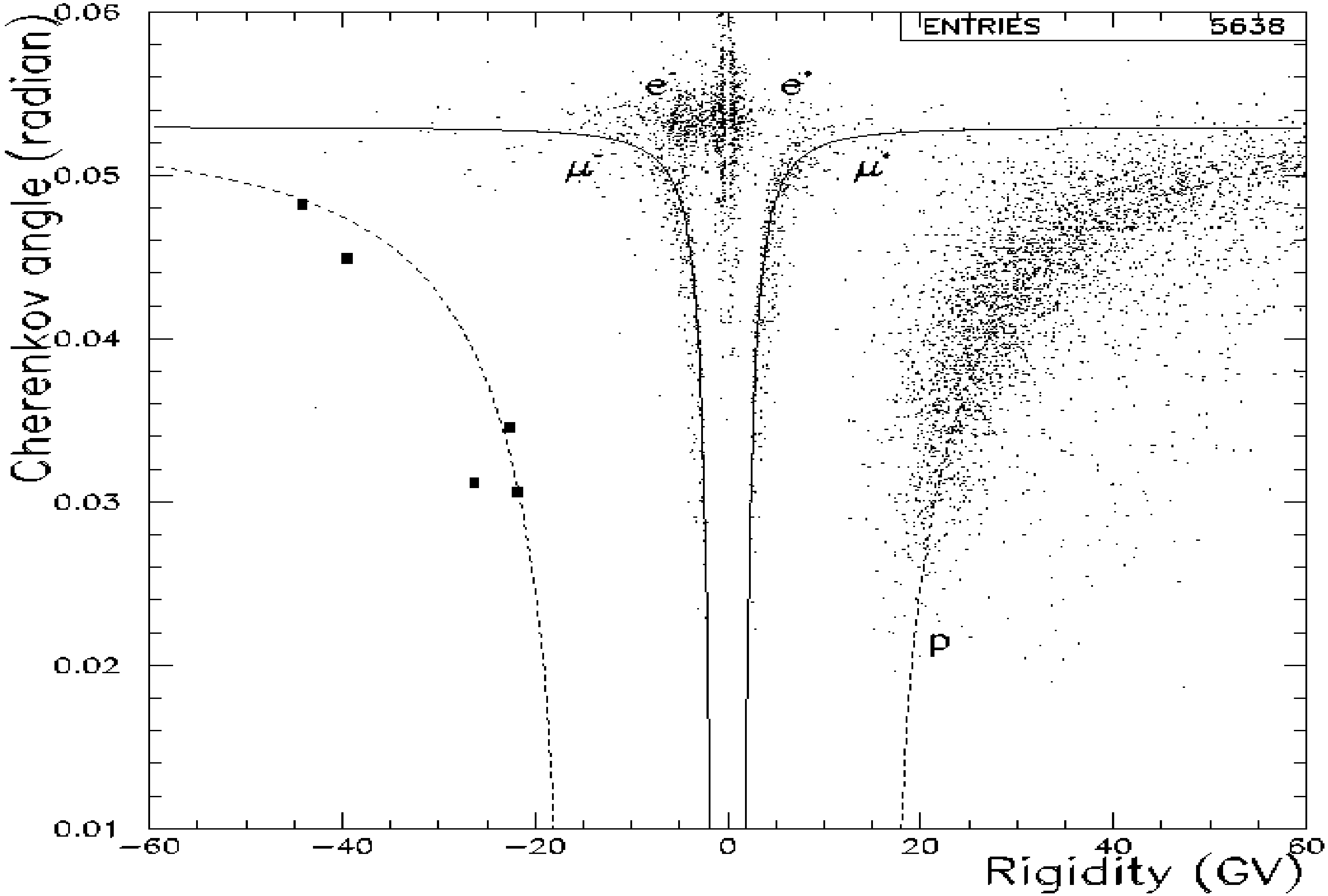
CAPRICE98 RICH counter





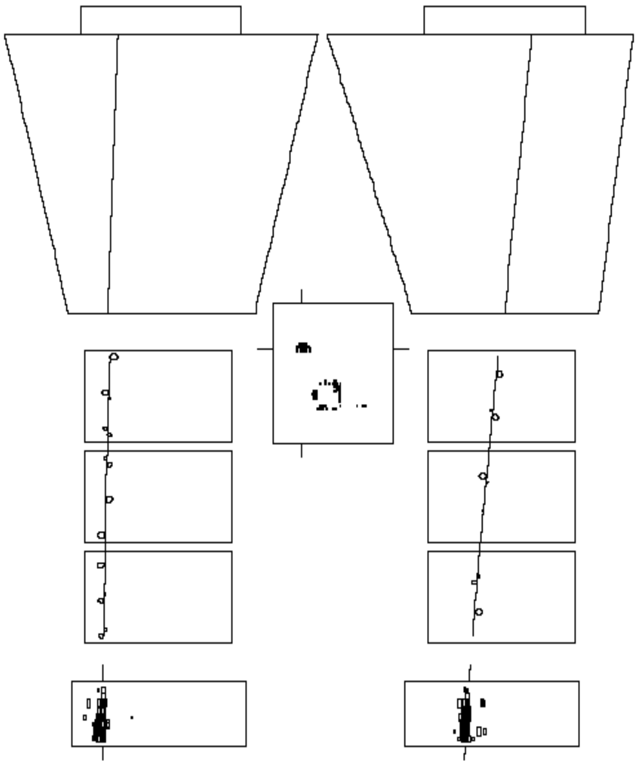


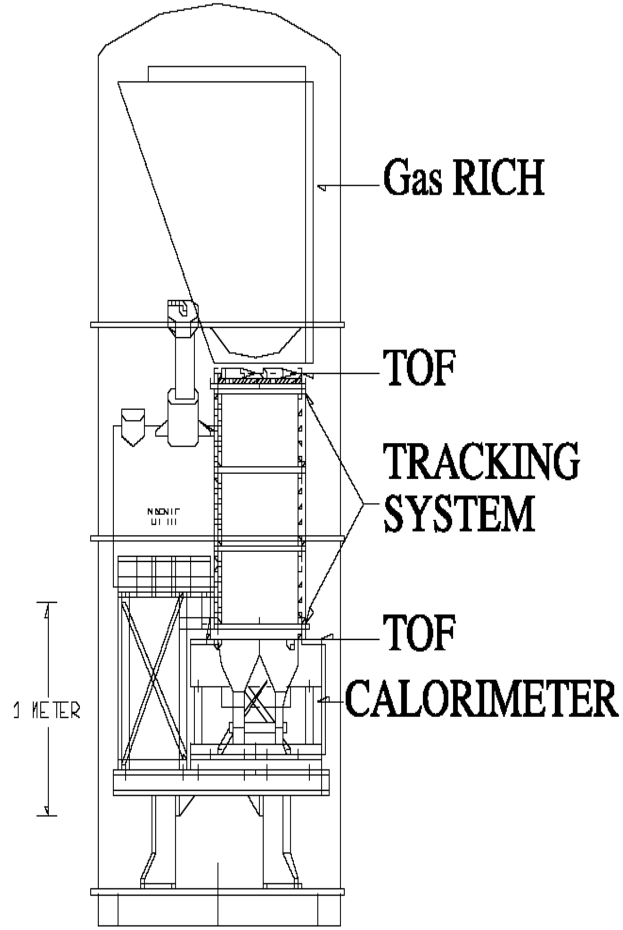
D. Bergström et al. Nucl.Instr. Meth A463(2001)161



CAPRICE98 RICH identification of high energy antiprotons

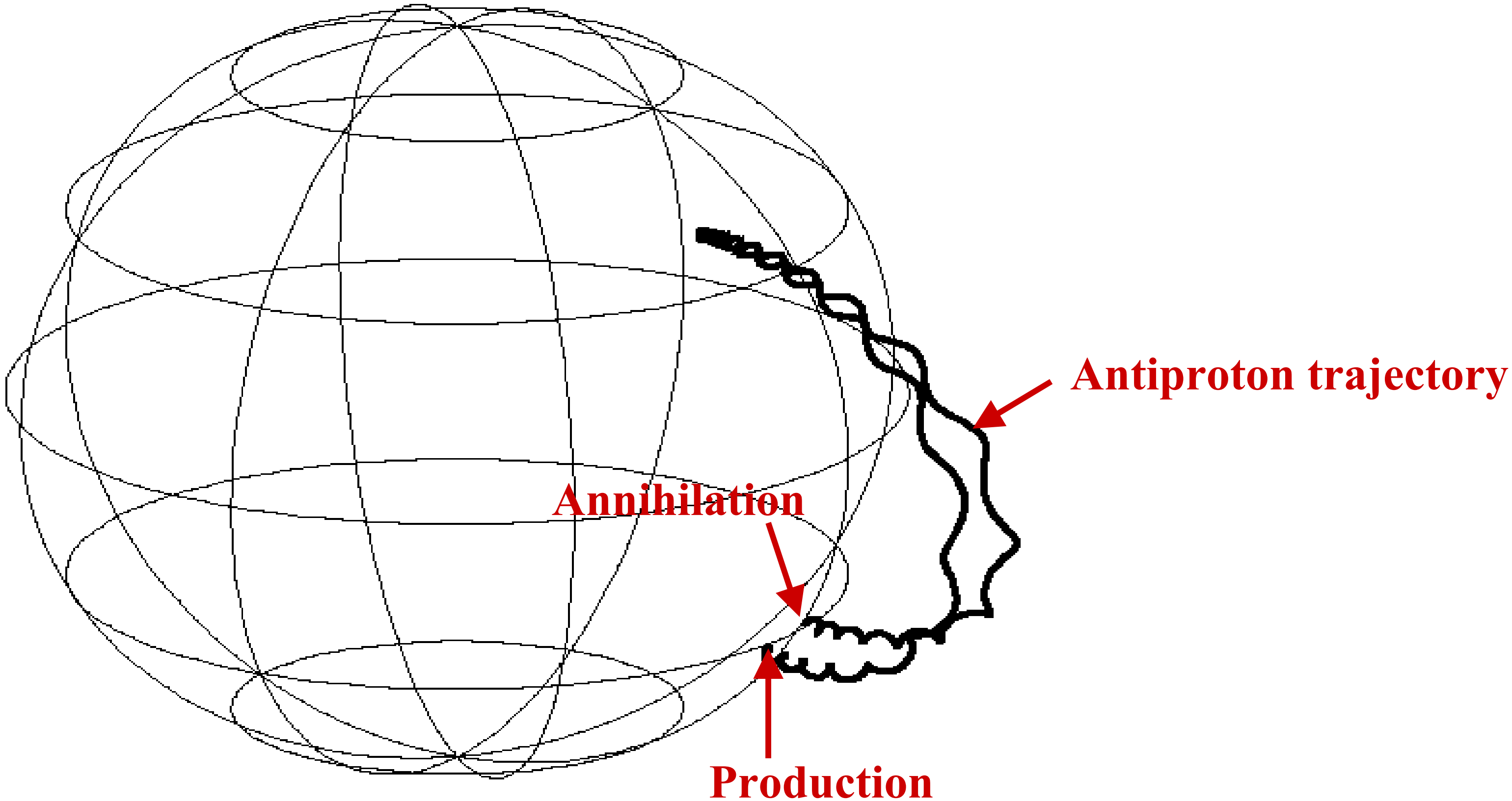
5 GeV electron





M. Boezio et al. ApJ 561(2001)787

Example *atmospheric* antiproton, single bounce, annihilating close to its production, 0.54 GeV



C.Y. Huang et al. astro-ph/0305367

Science with antiparticles

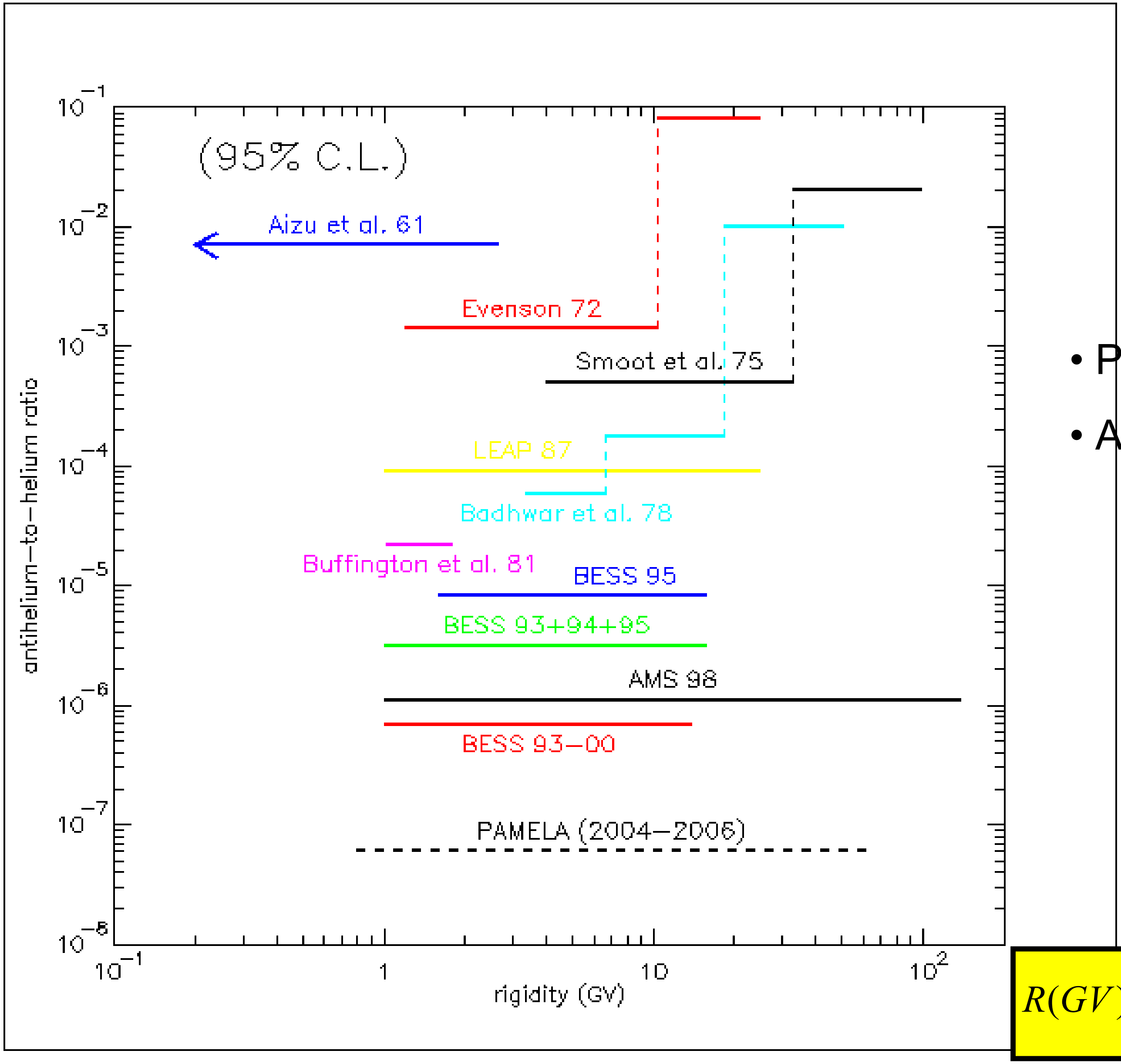
Antinuclei - Antiworlds

Positrons
Antiprotons

- Production and propagation in the galaxy
- Dark matter signals
- Primordial black holes

Cosmic-ray Antihelium Search

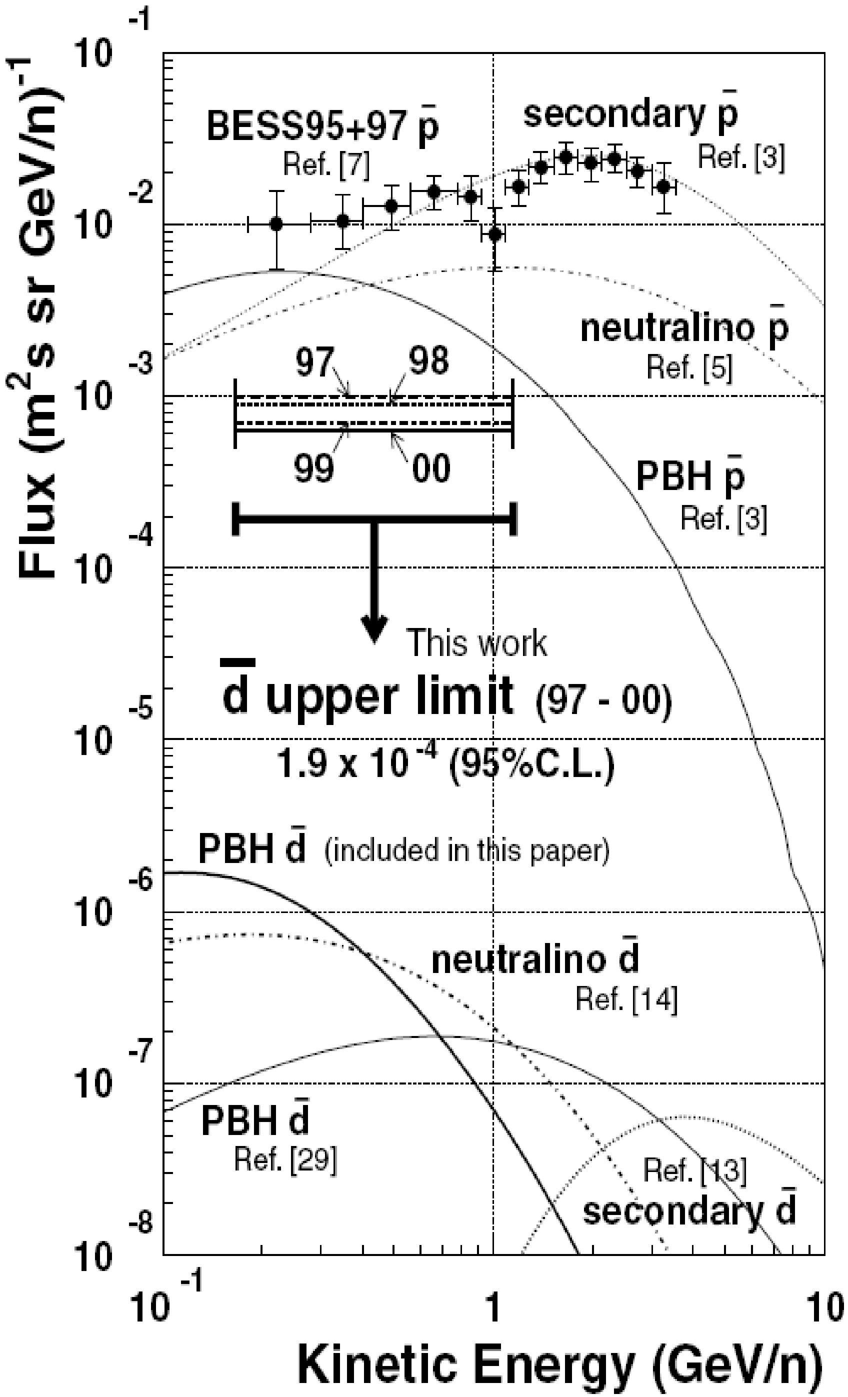
$\overline{\mathrm{He}}$ / He



- Primordial?
- Anti-star? ($\overline{\mathrm{C}}$)

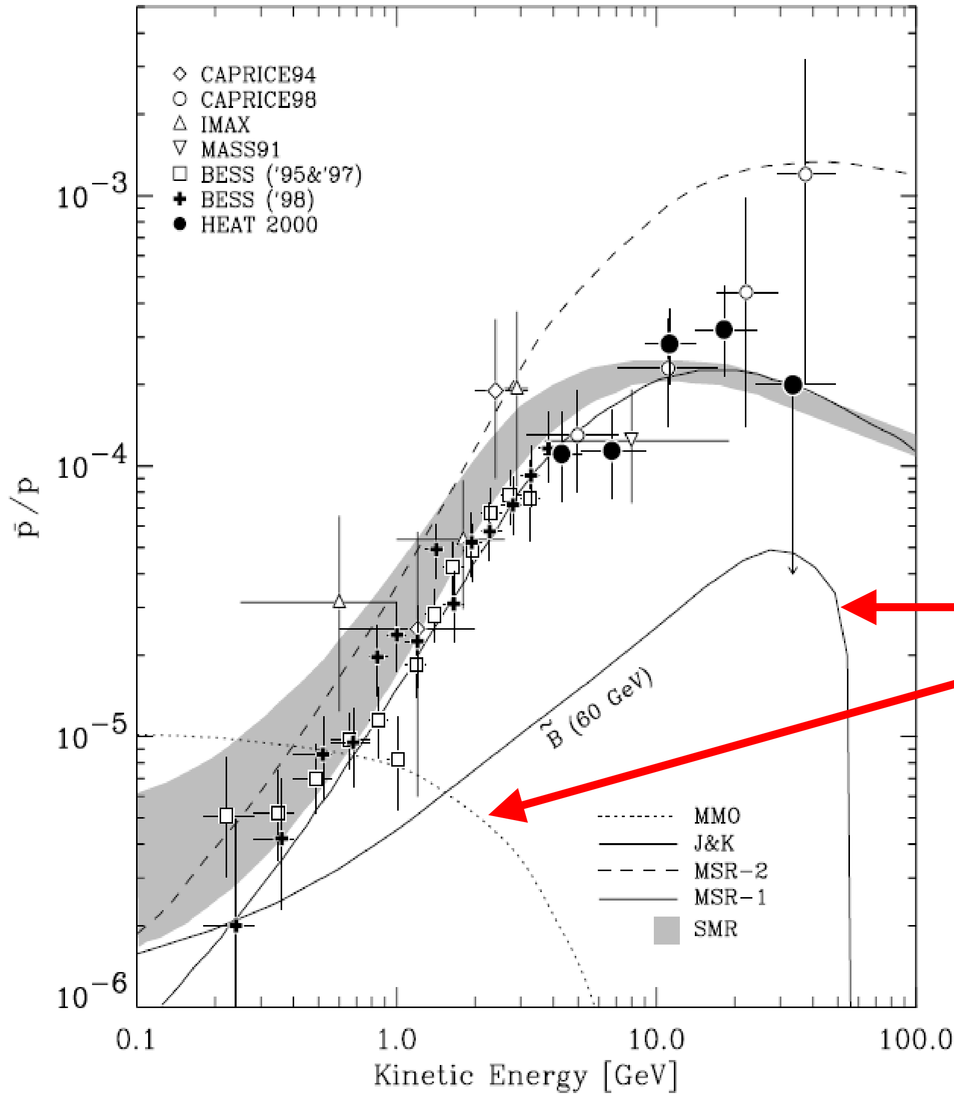
CR production ~O(10^{-14})

$$R(GV) = \frac{p(GeV)}{q(e)} = Br$$



Antideuterons

H. Fuke et al. Phys. Rev. Lett. 95(2005)081101



Compilation of data on antiproton/proton ratio

Possible contributions from

Neutralino Dark Matter

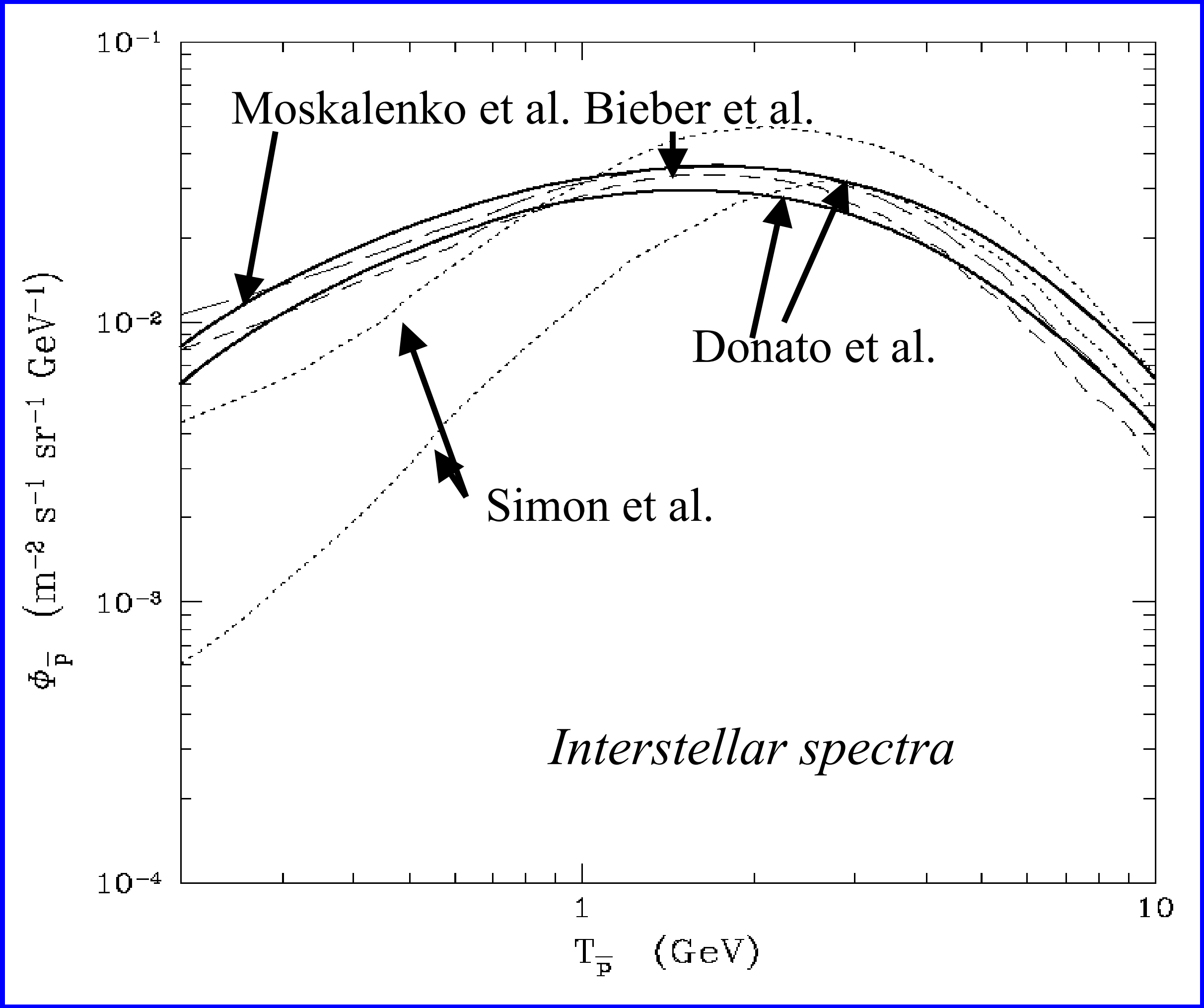
Primordial Black Holes

A.S. Beach et al. Phys. Rev. Lett. 87(2001)27110

ISM antiproton production
Issues:

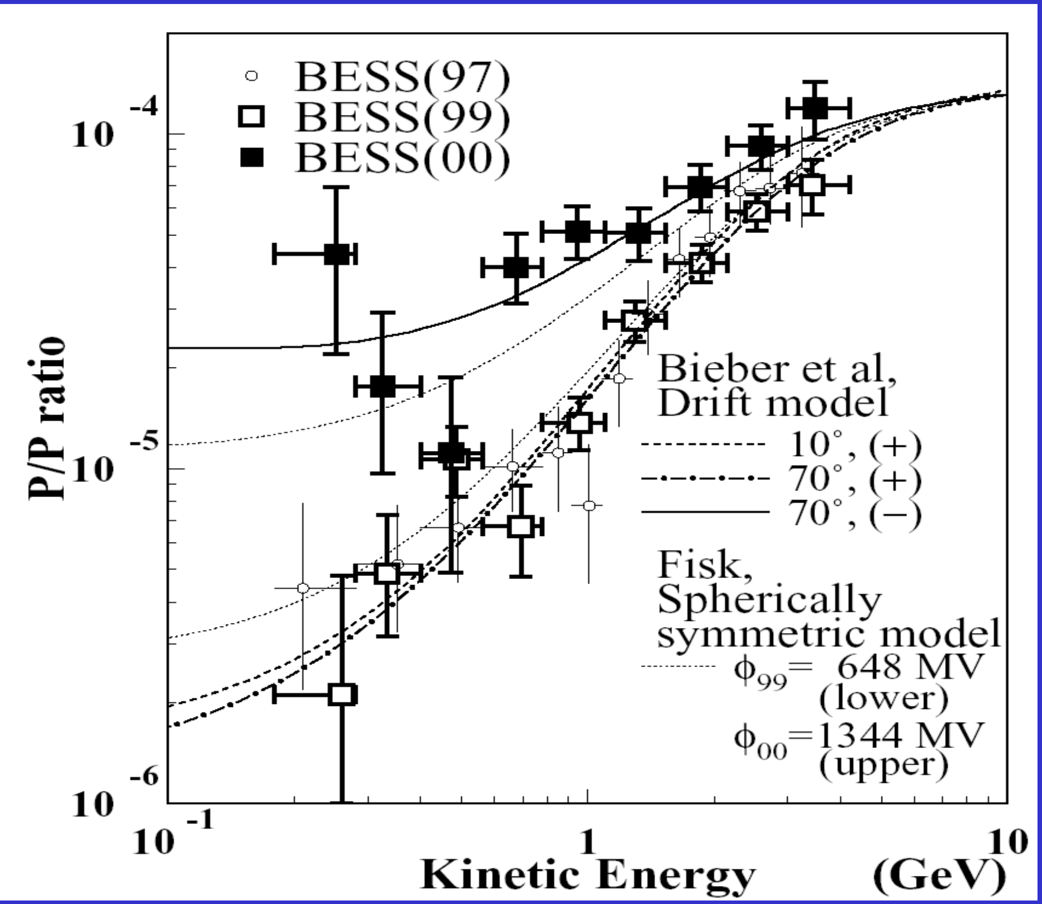
- Proton flux
- ISM distribution
- Antiproton production models
- IG magnetic field
- Solar modulation

Interstellar production of antiprotons



F. Donato et al. ApJ 563(2001)172

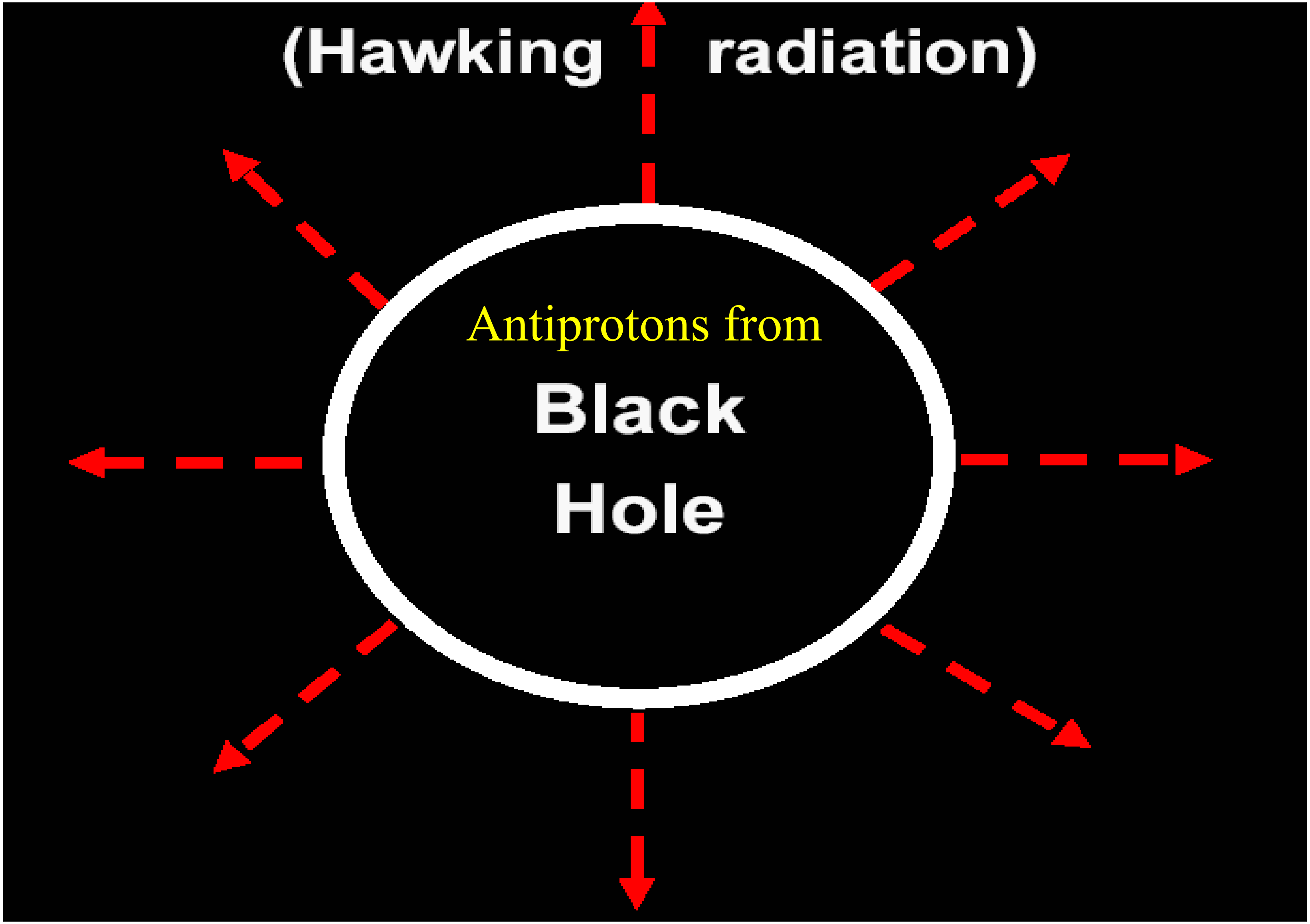
Solar Modulation Effects



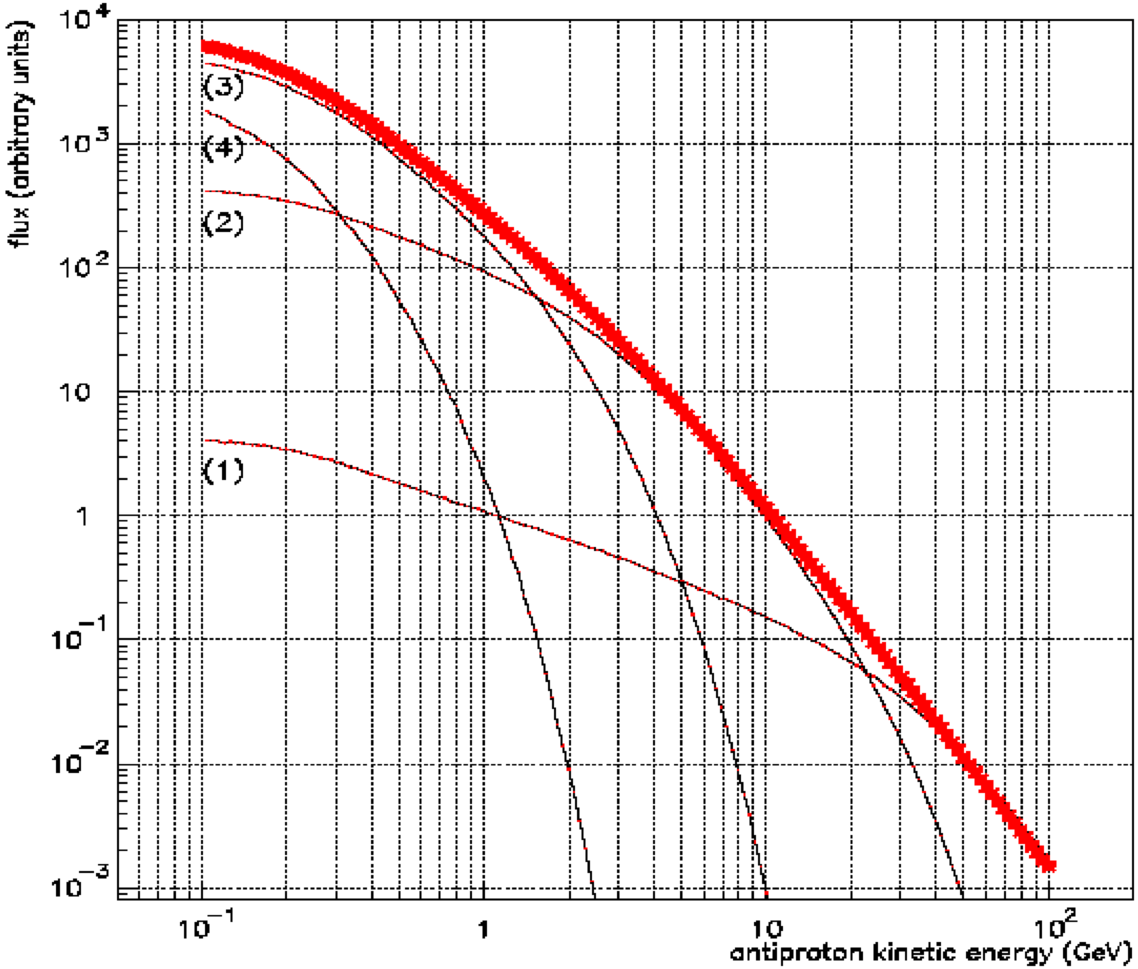
The solar magnetic field reversed polarity early 2000.

The <u>drift</u> model is characterized by a tilt angle of the heliospheric current sheet and the sun's magnetic polarity. The standard <u>spherically symmetric model</u> is characterized by one single parameter.

Y. Asaoka et al. astro-ph/0109007


(Hawking radiation)
Antiprotons from
Black
Hole

Initial antiproton spectrum from PBH



BH mass

(1) : < 10^{12} g

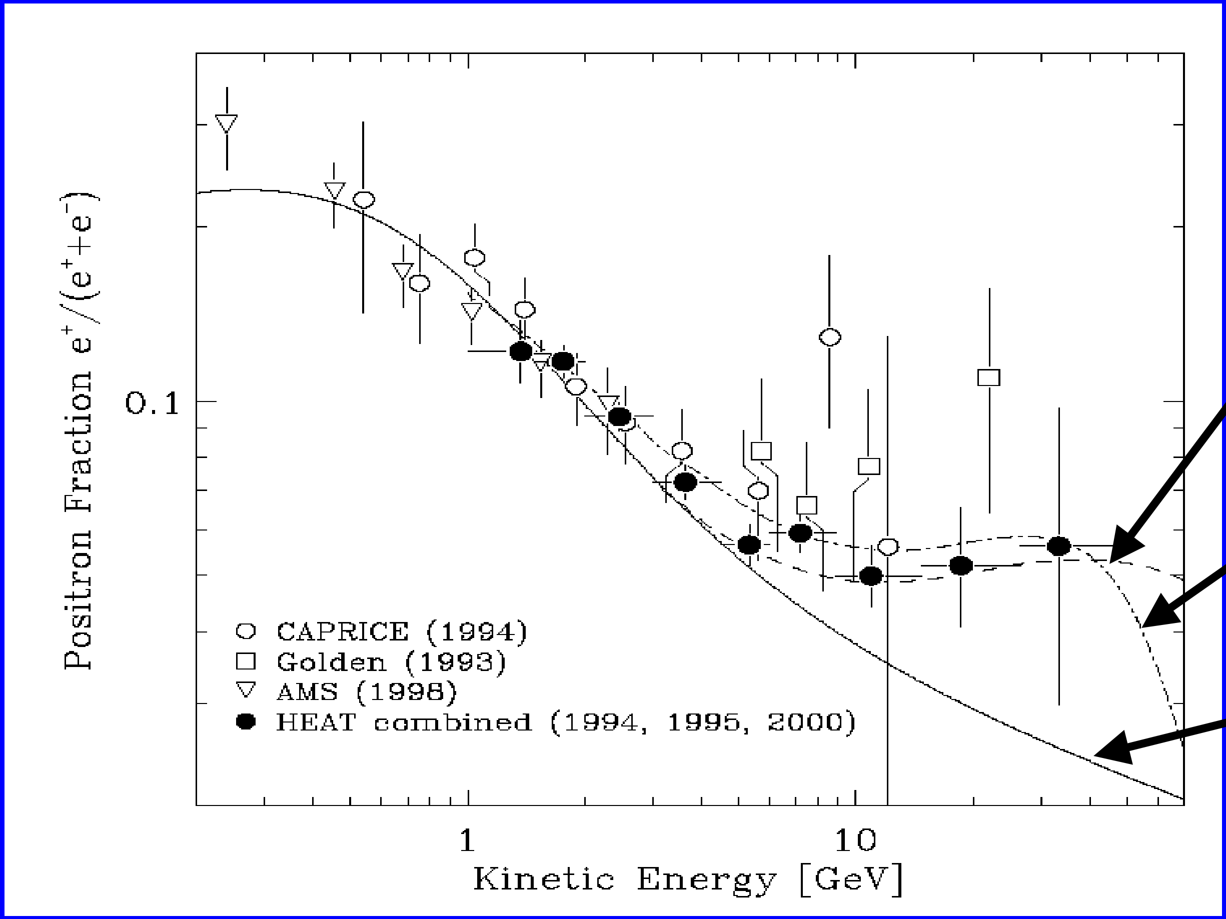
(4) : > 5×10^{13} g

A. Barrau et al. astro-ph/01124865

A Dark Matter Positron Signal

- Background: positrons created in hadronic interactions; electron-positron pairs created in electromagnetic interactions; radioactive nuclei ejected in Super Nova blasts
- Spectral features necessary, not just a flux.

New positron data from HEAT – combined 1994, 1995 and 2000 data

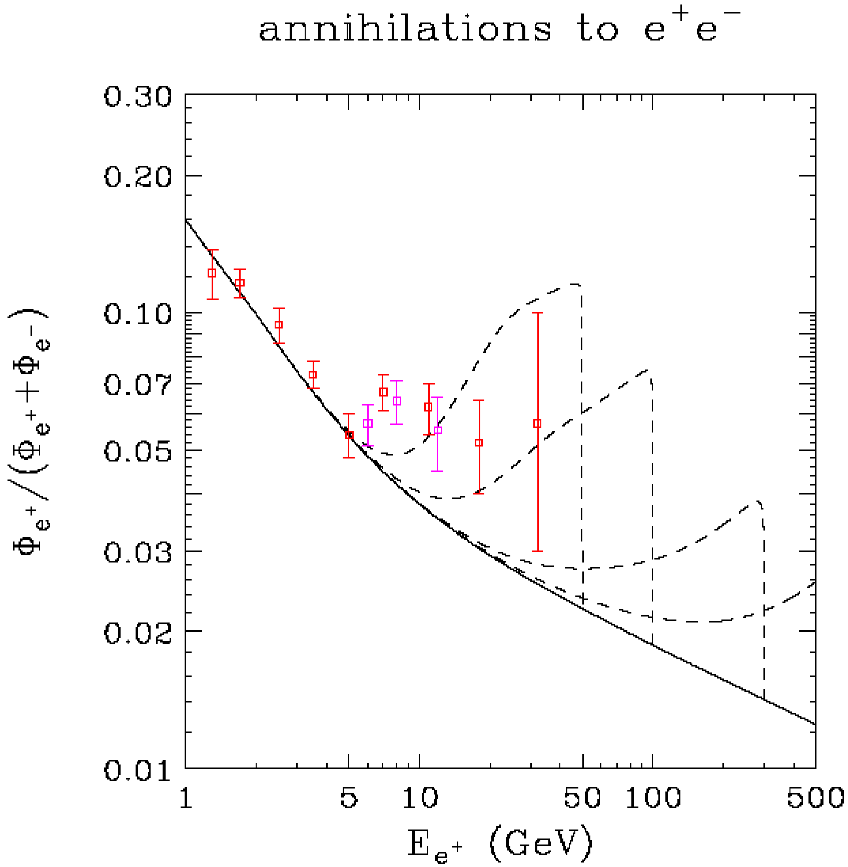


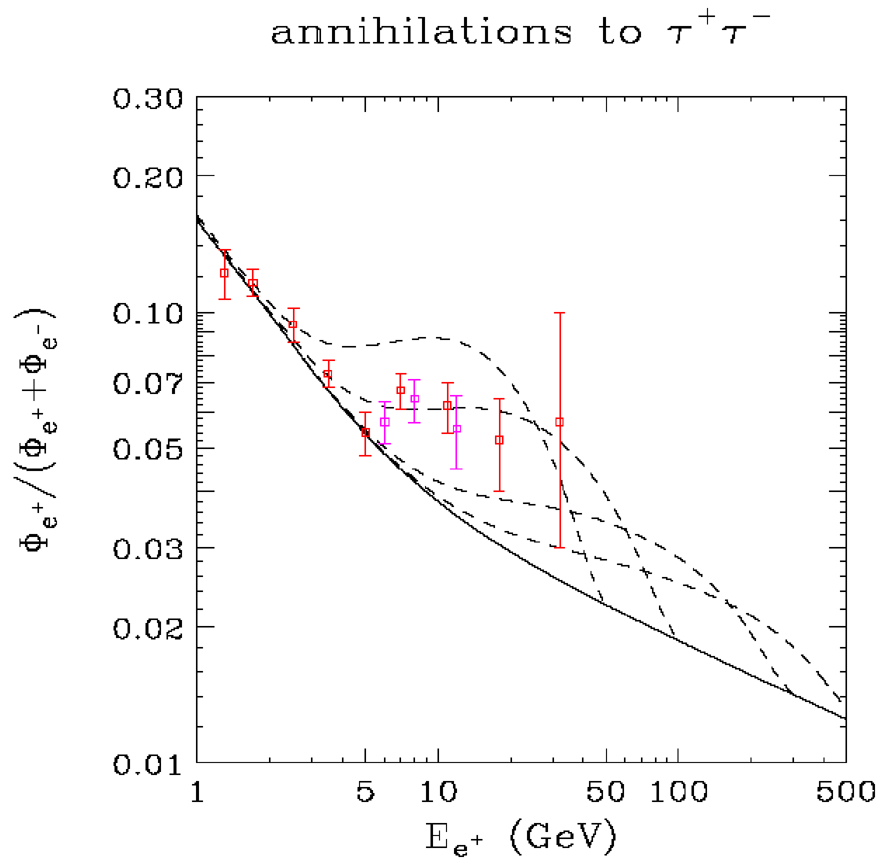
LSP Dark Matter contribution

Positrons from gamma-ray pulsars

Background, Moskalenko and Strong

Beatty et al. astro-ph/0412230



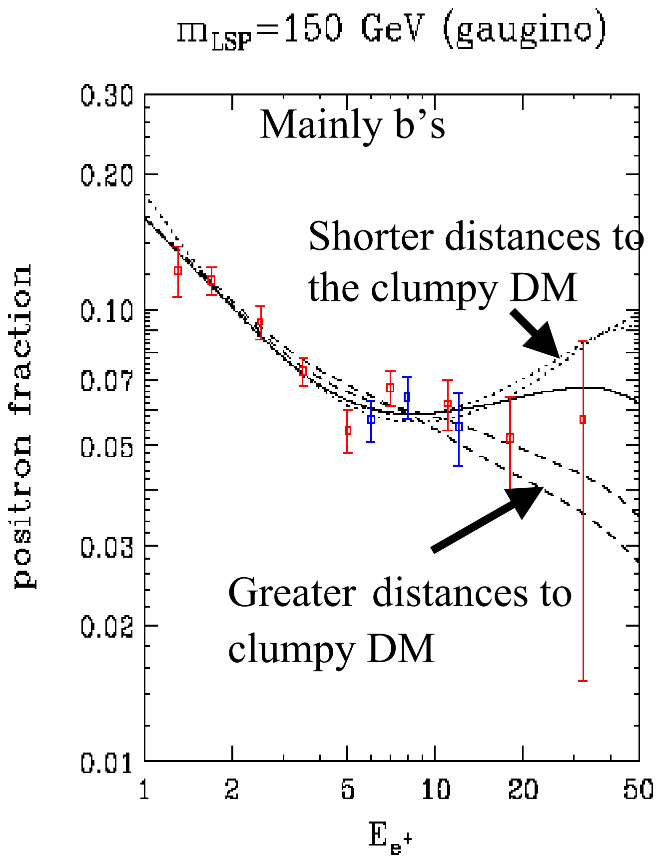


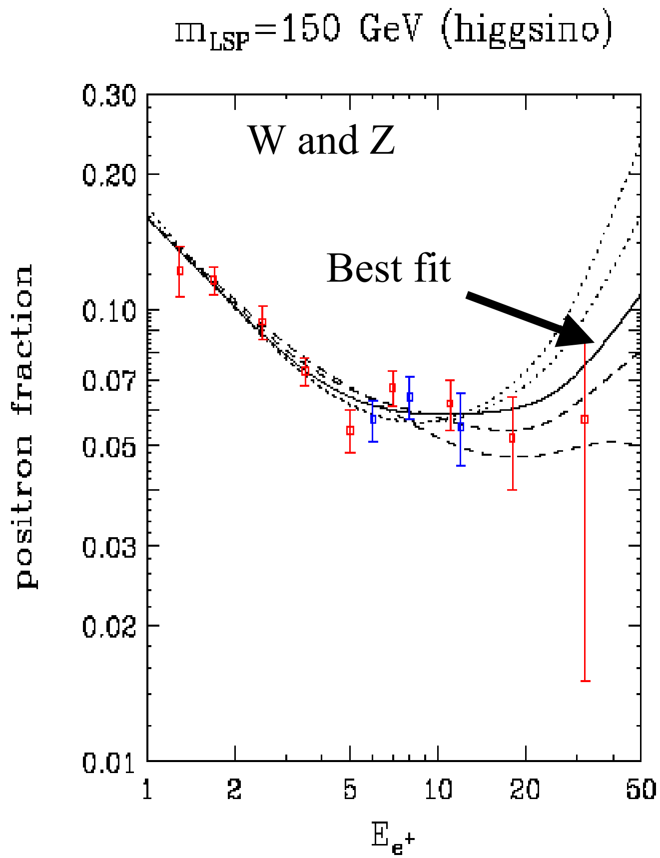
Positron fraction for WIMP masses 50, 100, 300, 600 GeV. Boost factor 5. Local density 0.43 GeV/cm^3. Data from HEAT.

Hooper and Silk hep-ph/0409104

Positron fraction after propagation

Different lines represent different distances to the dark matter clump, about 0.5 kpc for the two cases. Data from the HEAT experiment.



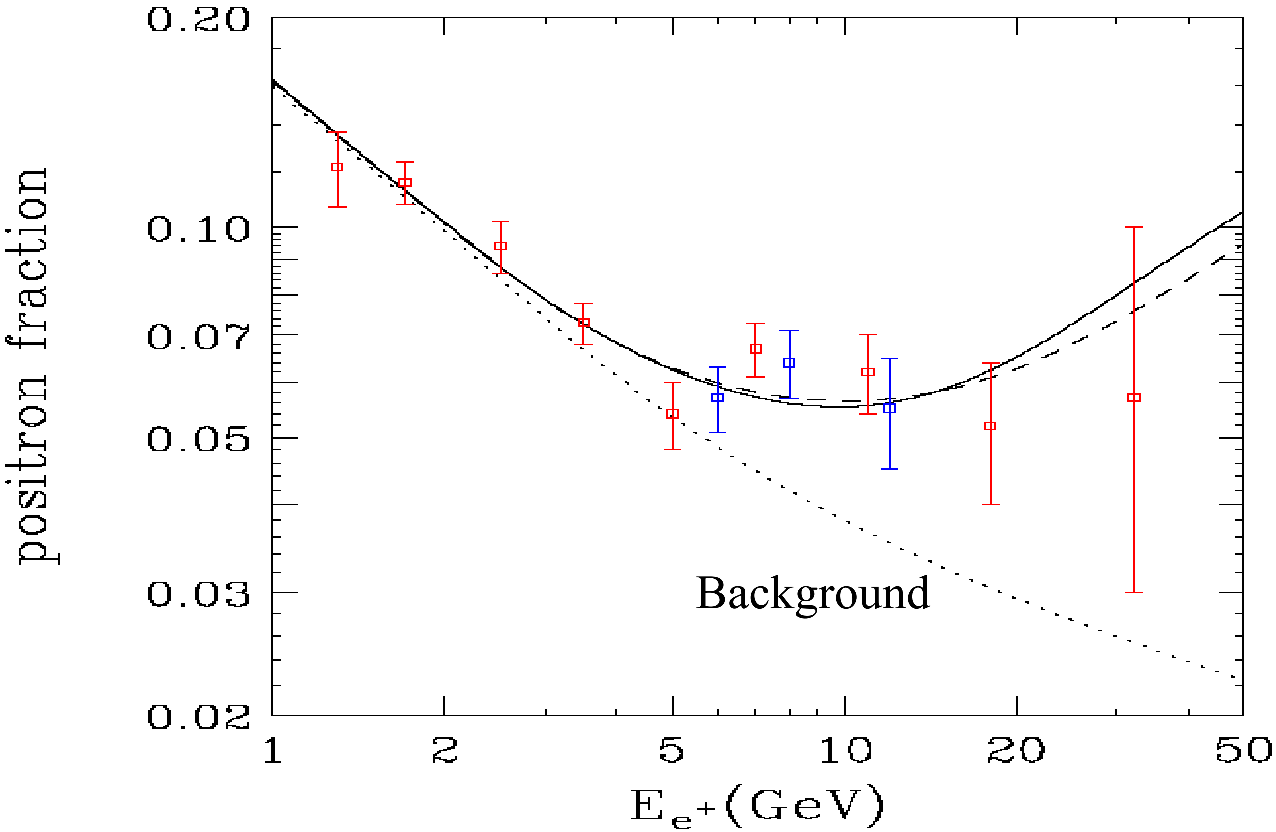


G. Bertone et al hep-ph/0404175

Kaluza-Klein Dark Matter signals

- KK particles first proposed in 1920's
- Models with extra spatial dimensions $\Rightarrow$ tower of KK particles. Compactification $\Rightarrow$ lightest KK particle stable
- KK particles are *cold bosonic* dark matter, non relativistic
- To match the cold Dark Matter measured by WMAP the preferred mass is in the range 700 – 1000 GeV. In certain models mass may be as low as 250 – 300 GeV.
- KK particles are bosons and annihilate *directly* to electron-positron pairs as compared to neutralino annihilations into fermions that are chirality suppressed.

Positron fraction from KK dark matter after propagation



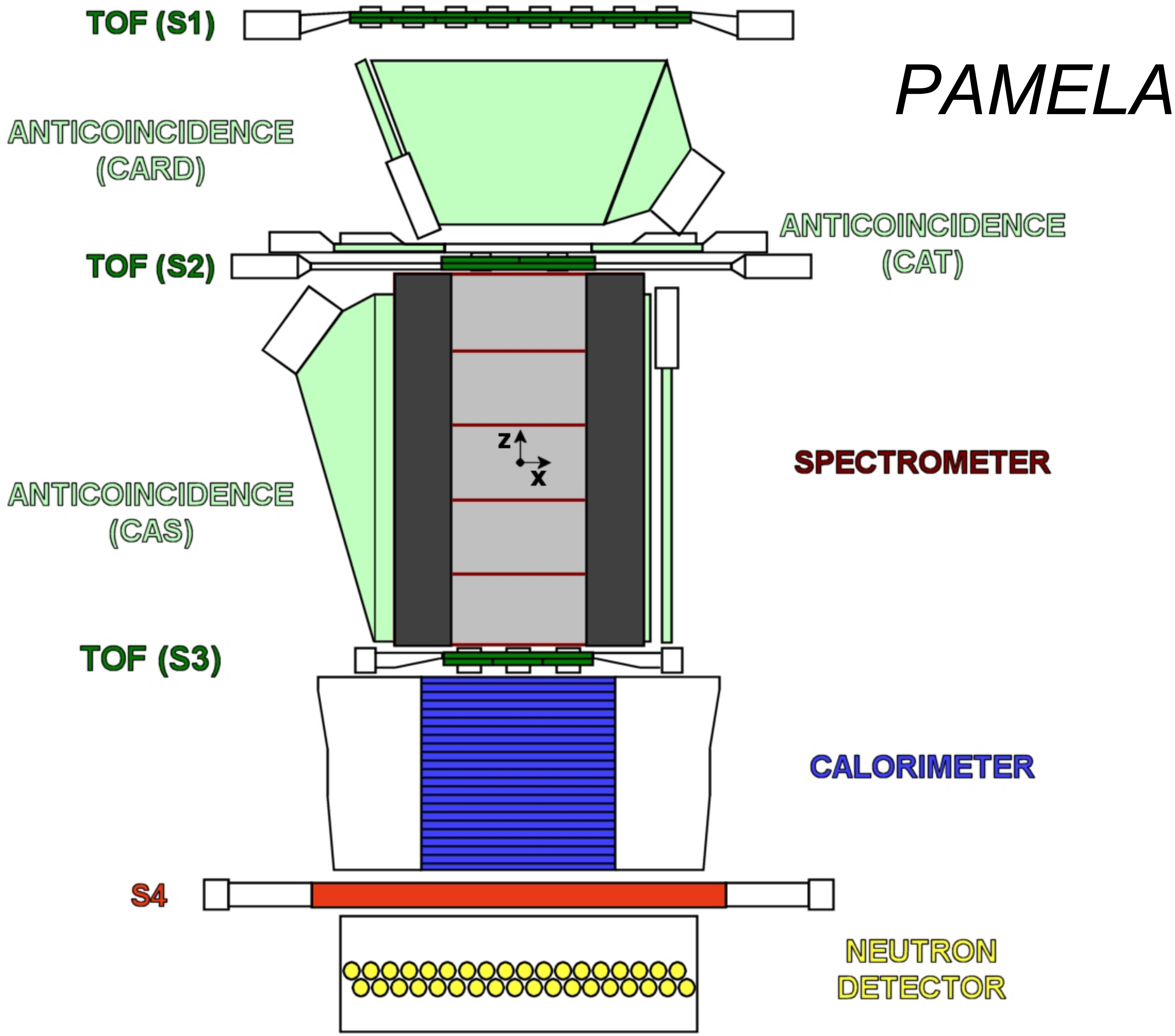
Data from the HEAT experiment.

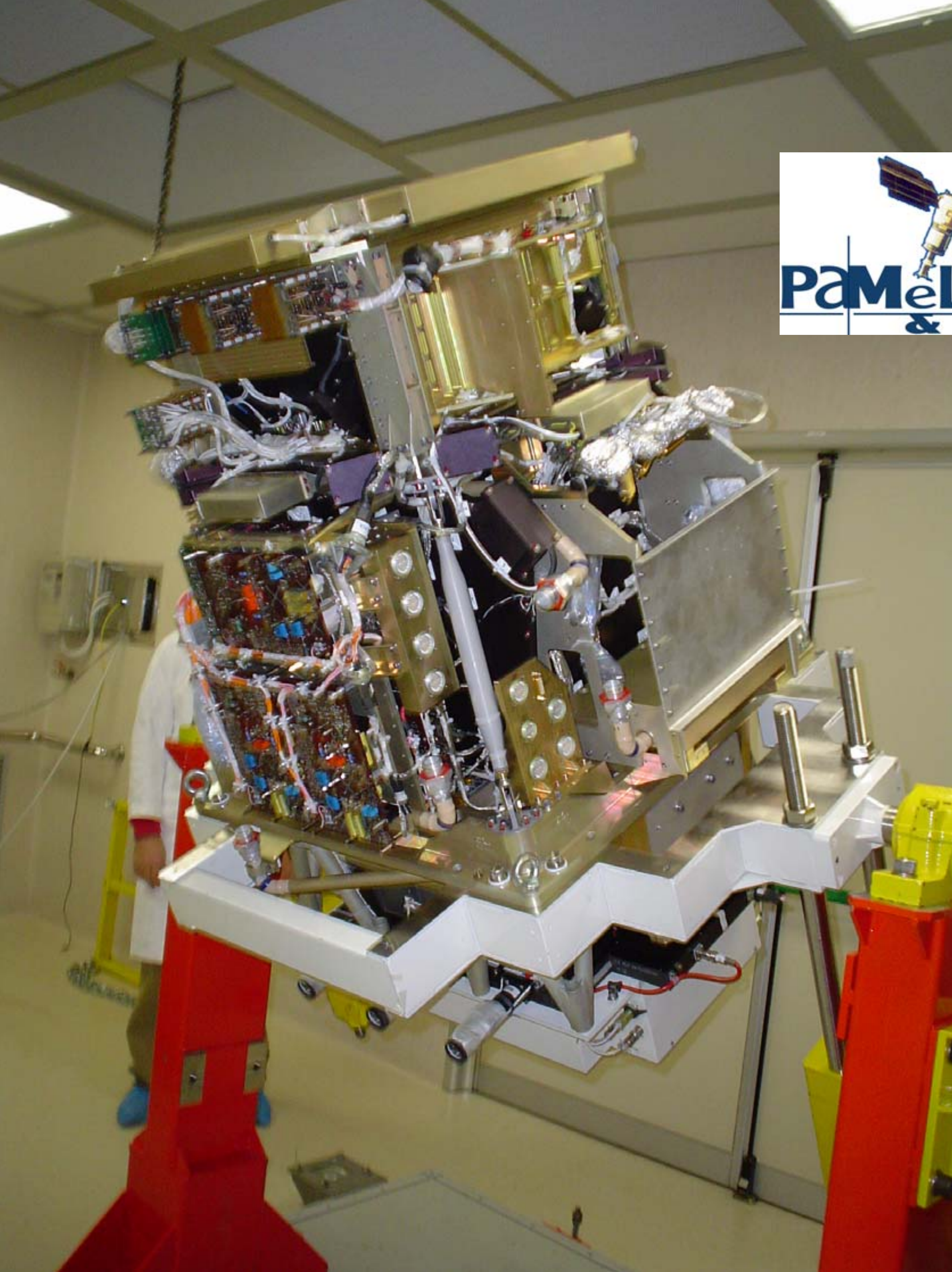
The positron fraction for two values of KK B^1 masses are shown, 300 and 600 GeV.

D. Hooper and G.D. Kribs hep-ph/0406026

The future:

- Long duration balloon flights
- Satellite experiment PAMELA
- ISS experiment AMS


PAMELA
TOF (S1)
ANTICOINCIDENCE (CARD)
ANTICOINCIDENCE (CAT)
TOF (S2)
SPECTROMETER
z
x
ANTICOINCIDENCE (CAS)
TOF (S3)
CALORIMETER
S4
NEUTRON DETECTOR



PaMeLa

a Payload for Antimatter Matter Exploration and Light–nuclei Astrophysics

Particle	Number (3 yrs)	Energy Range
Protons	3.10^{8}	80 MeV - 700 GeV
Antiprotons	**$>3.10^{4}$**	**80 MeV - 190 GeV**
Electrons	6.10^{6}	50 MeV - 2 TeV
Positrons	**$>3.10^{5}$**	**50 MeV - 270 GeV**
He	4.10^{7}	80 MeV/n - 300 GeV/n
Be	4.10^{4}	80 MeV/n - 300 GeV/n
C	4.10^{5}	80 MeV/n - 300 GeV/n
Antihelium Limit (90% C.L.)	**7.10^{-8}**	**80 MeV/n - 30 GeV/n**

The PAMELA Collaboration

Germany: Universität Gesamthochschule Siegen

Siegen

Sweden: Kungl Tekniska Högskolan

KTH, Stockholm

Russia:

Физический Институт

Ioffe Physico-Technical Institute

Moscow
St. Petersburg

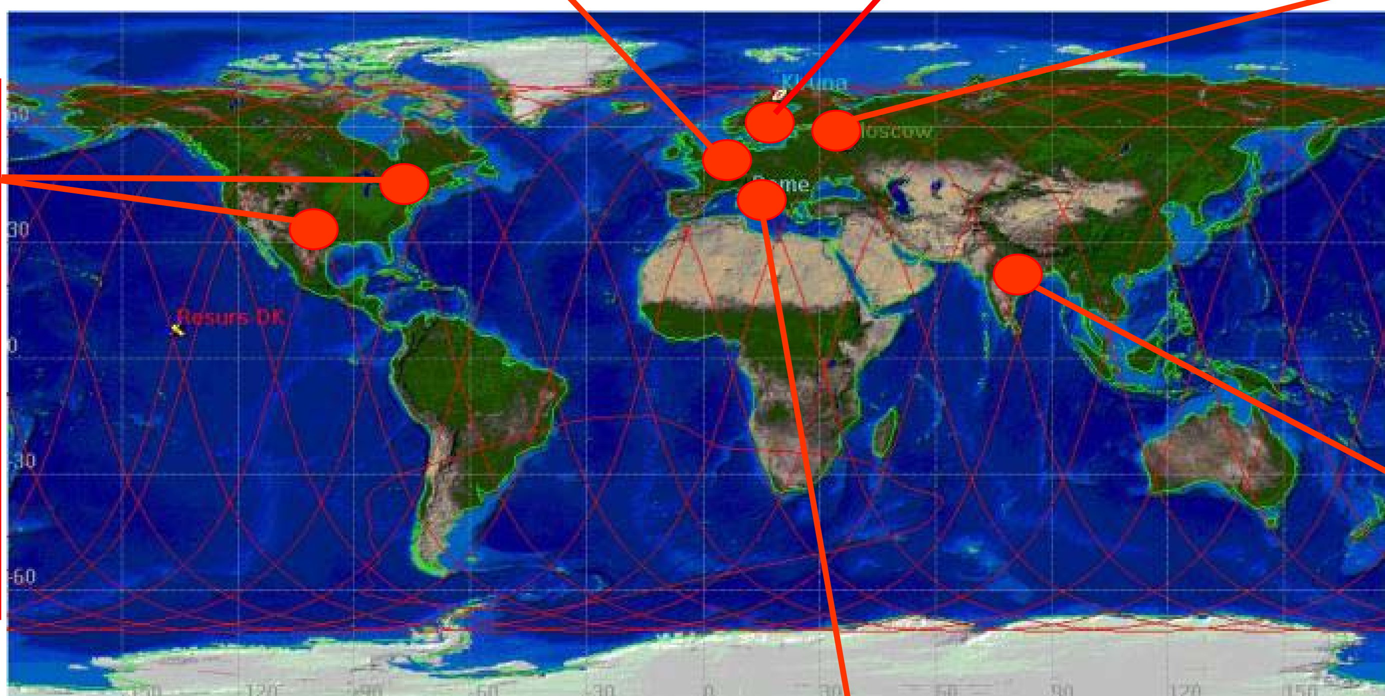
USA:

NASA

GSFC

New Mexico State University

NMSU



India:

TIFR
Tata Institute of Fundamental Research

Bombay

Italy:

Bari

Florence

LNF
Frascati

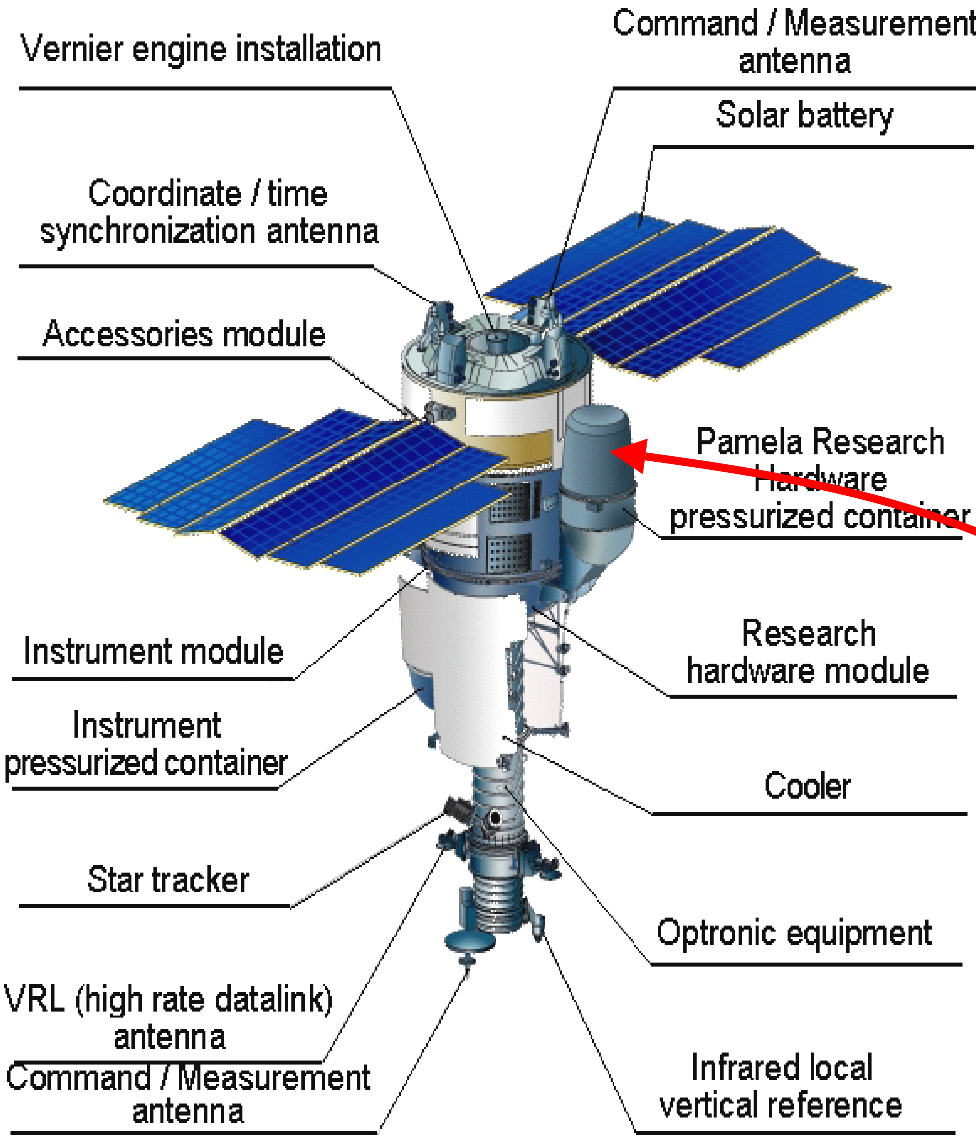
Naples

Tor Vergata
Rome

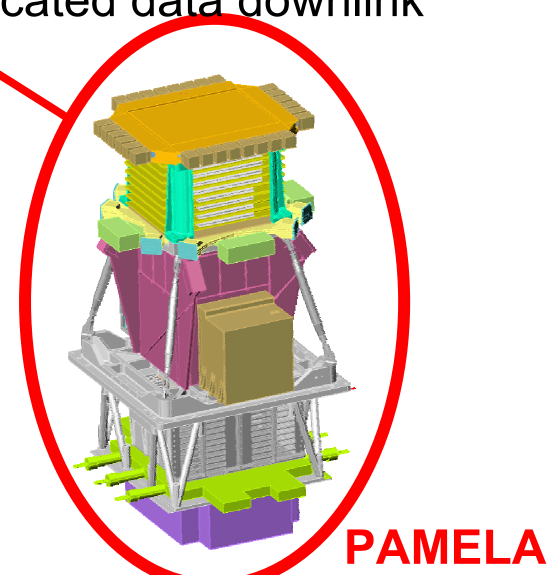
Trieste

IFAC
CNR, Florence

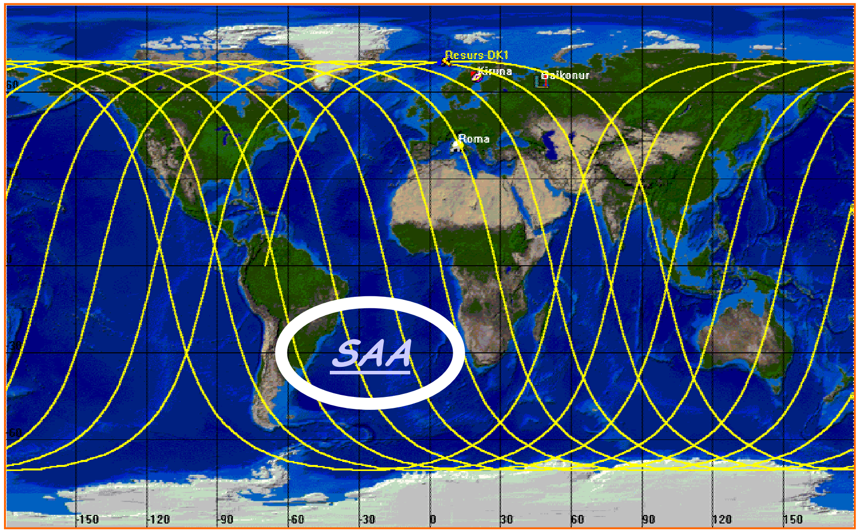
The Satellite: Resurs DK1

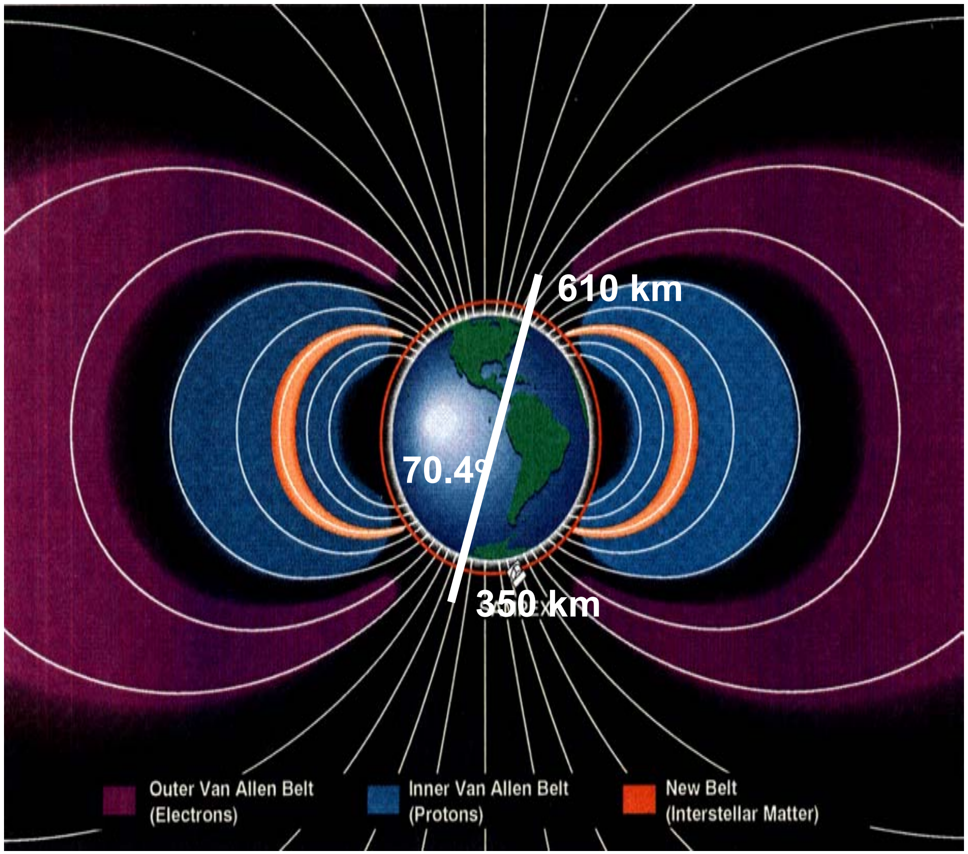


- Earth-observation satellite
- Souyez-TM launcher from Baikonur
- Launch early 2006
- PAMELA is mounted inside a pressurised container (5°C → 35°C)
- Dedicated data downlink



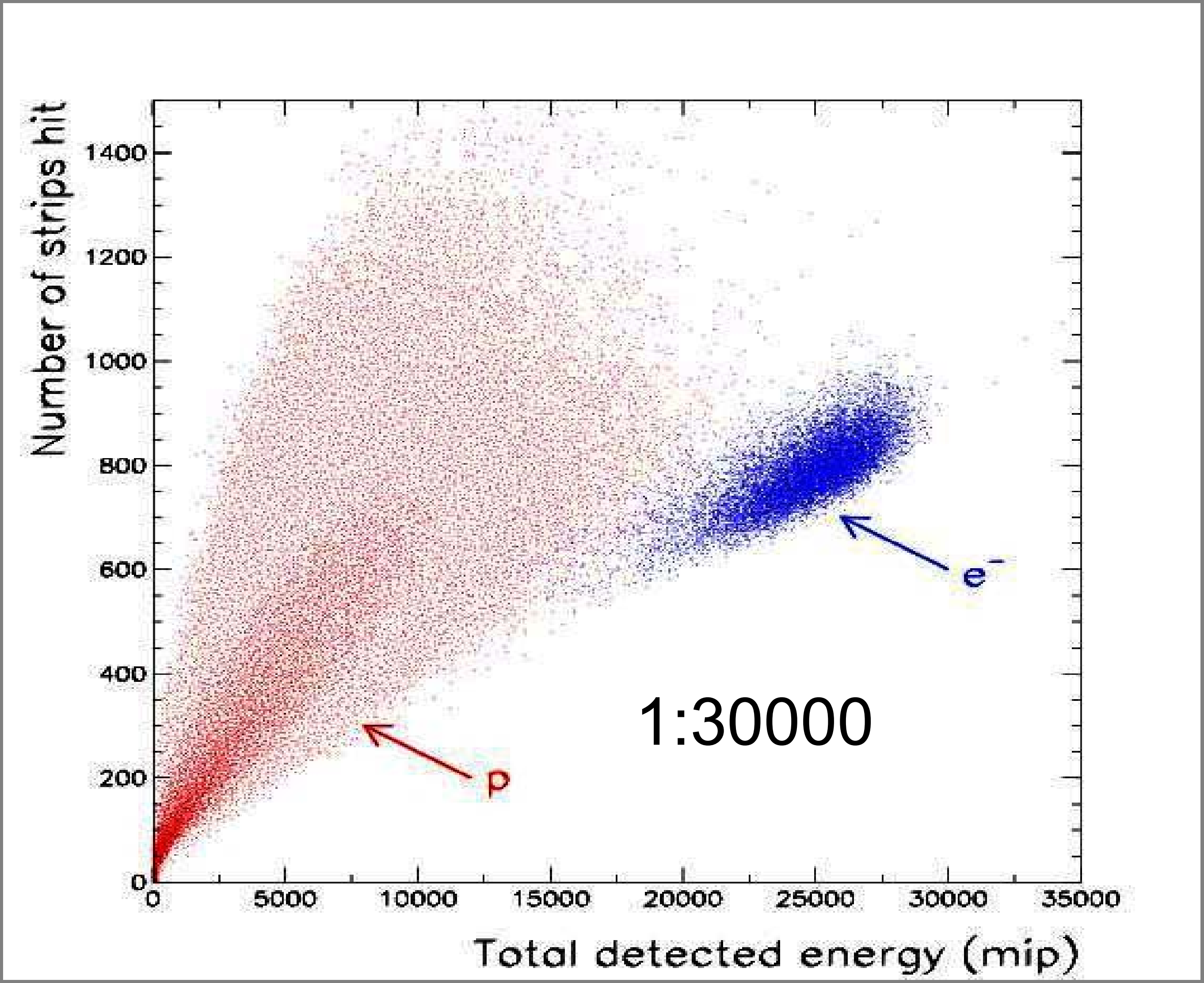
Orbit Characteristics





- Low-earth elliptical orbit
- 350 – 610 km
- Quasi-polar (70.4^{o} inclination)
- Lifetime >3 years (assisted)
- Electronics receive ~3 krad (qualify commercial parts)

e-p separation PAMELA calorimeter



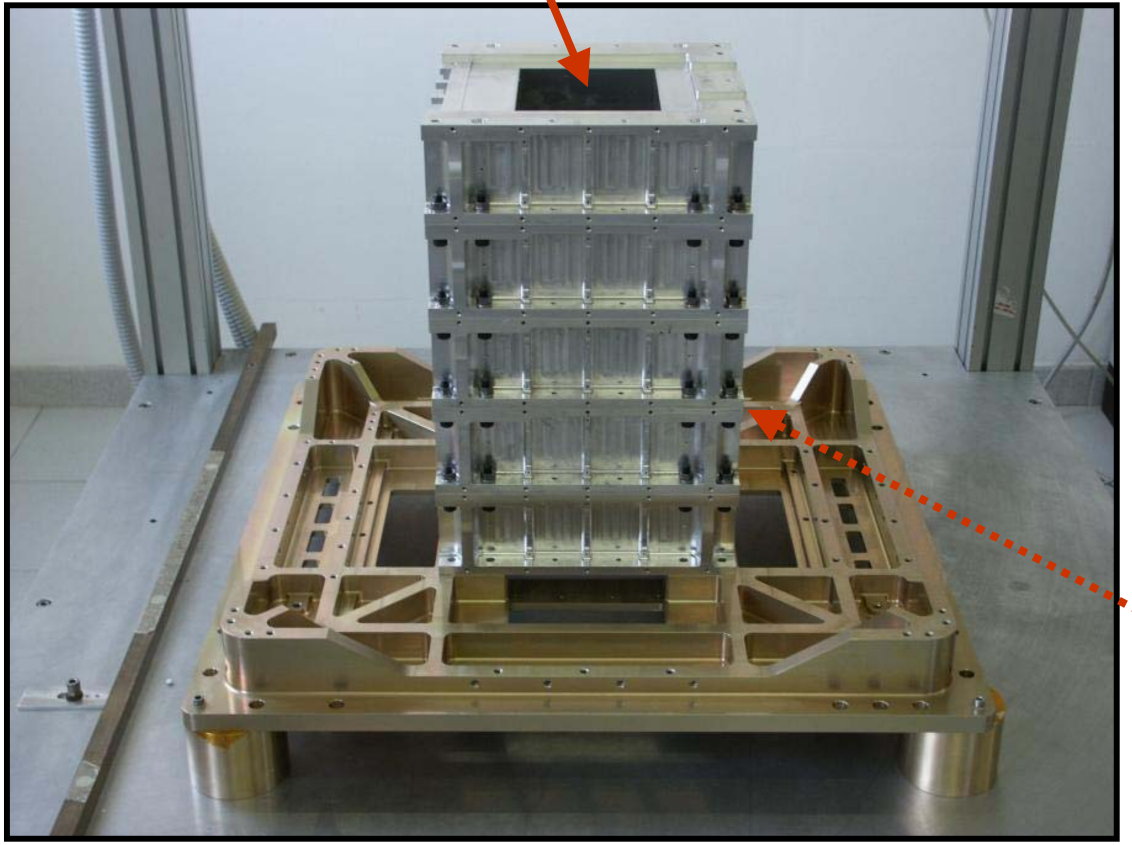
Test beam results, 200 GeV/c

Magnetic Spectrometer

Permanent magnet:

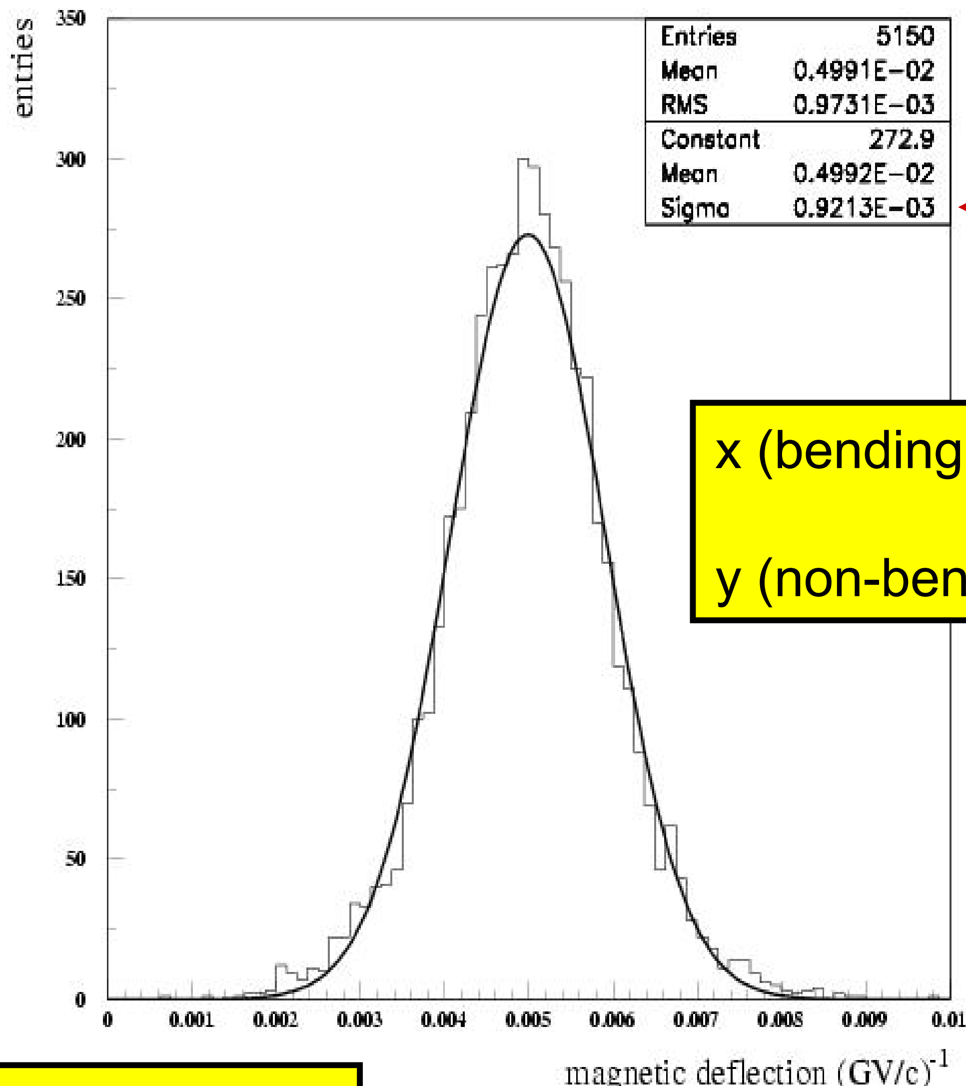
- 5 blocks of Nd-B-Fe
- 0.48 T at centre of cavity
- Magnetic tower = ($13.2 \times 16.2\ cm^2$) x 44.5 cm high

$\Rightarrow$ Geometric factor: $20.5\ cm^2\ sr$



Tracking system:
6 layers of double-sided silicon microstrips

Spectrometer Resolution



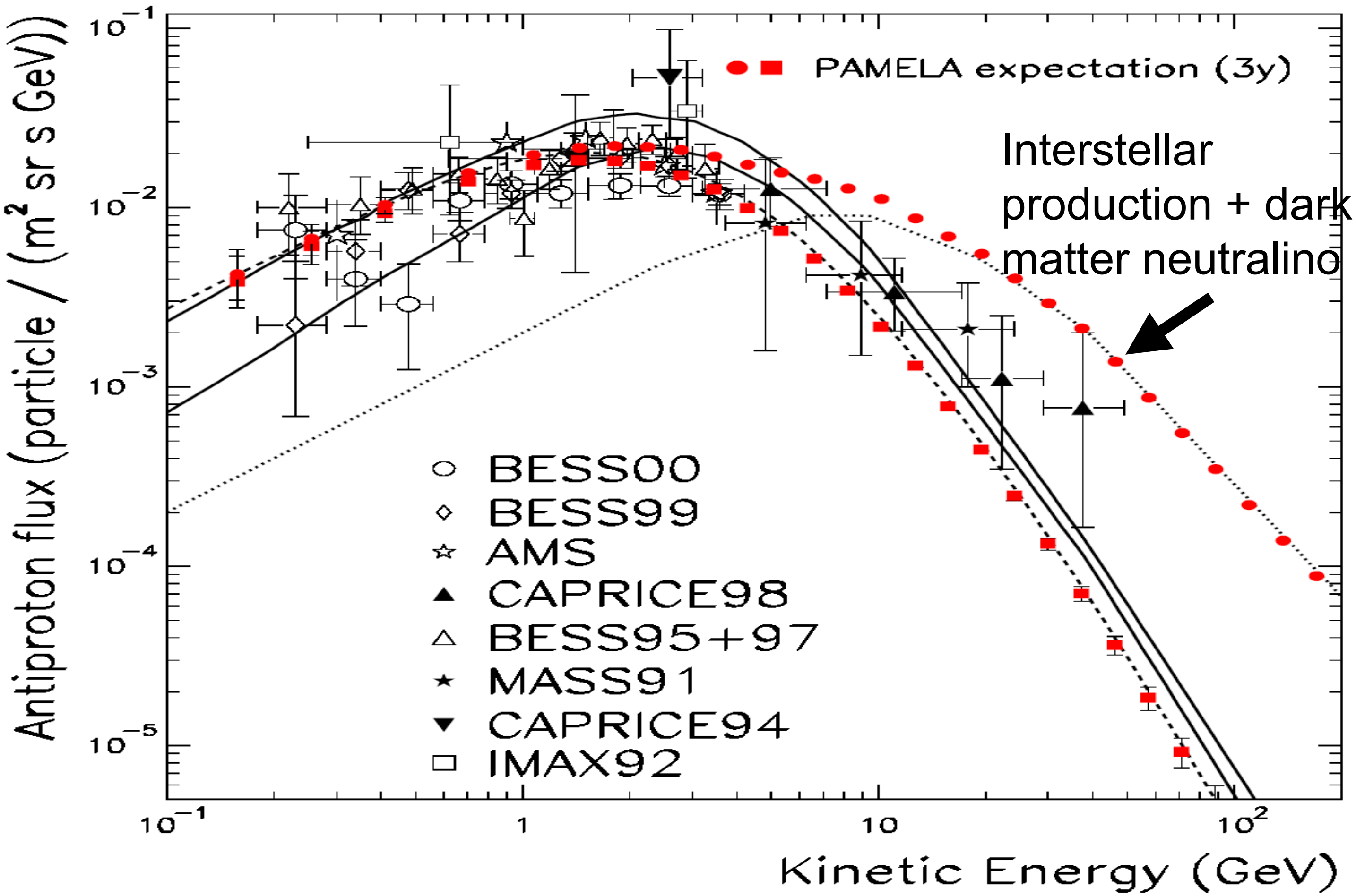
MDR ≅ 1080 GV (Δp/p = 1)

x (bending) resolution = 2.7 μm

y (non-bending) resolution = 12 μm

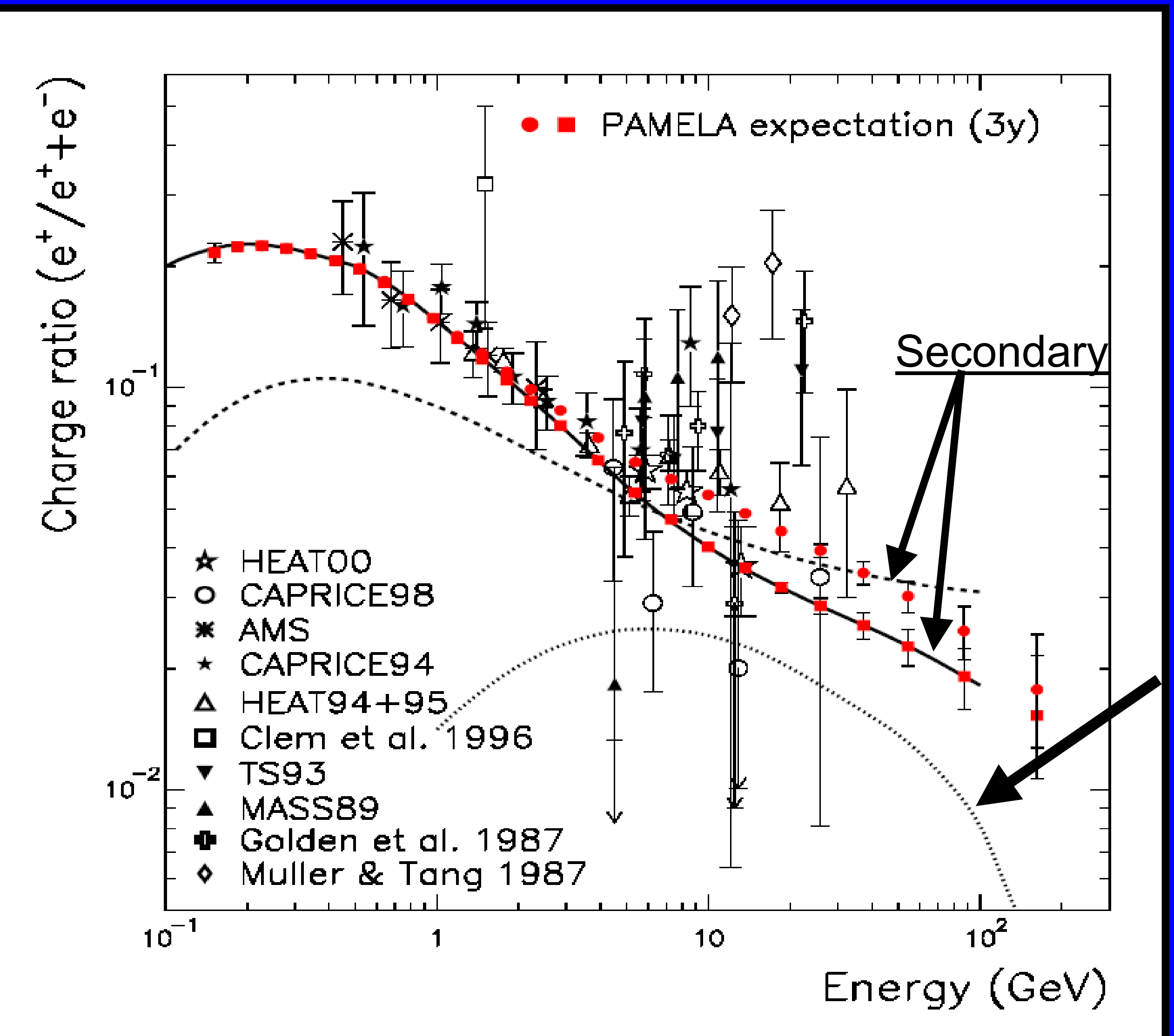
SPS Testbeam data: p 200 GeV/c

Antiprotons in PAMELA



M Boezio, ICRC Pune 2005

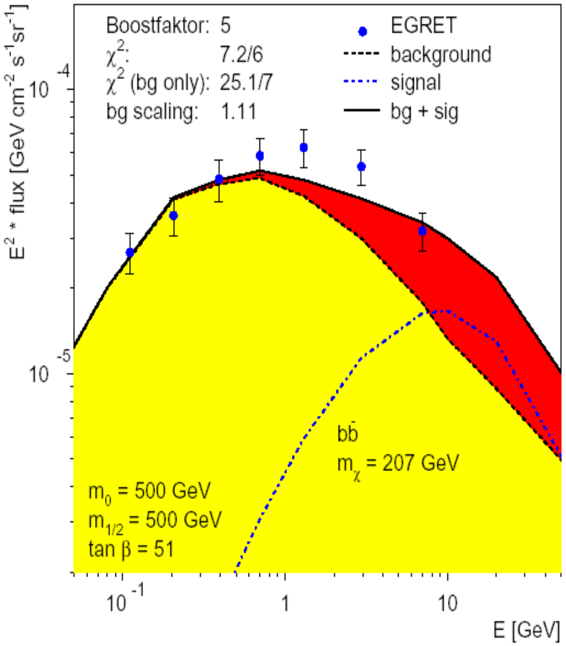
Positrons/electrons in PAMELA



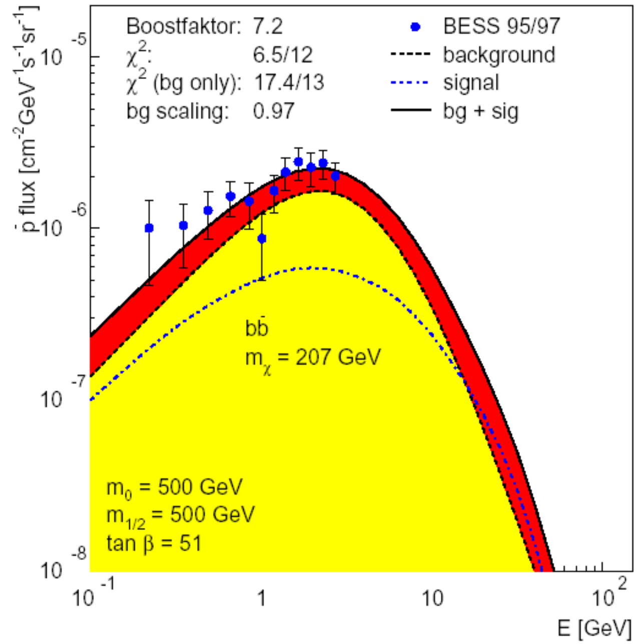
Dark matter neutralino contribution, m = 336 GeV

M Boezio, ICRC Pune 2005

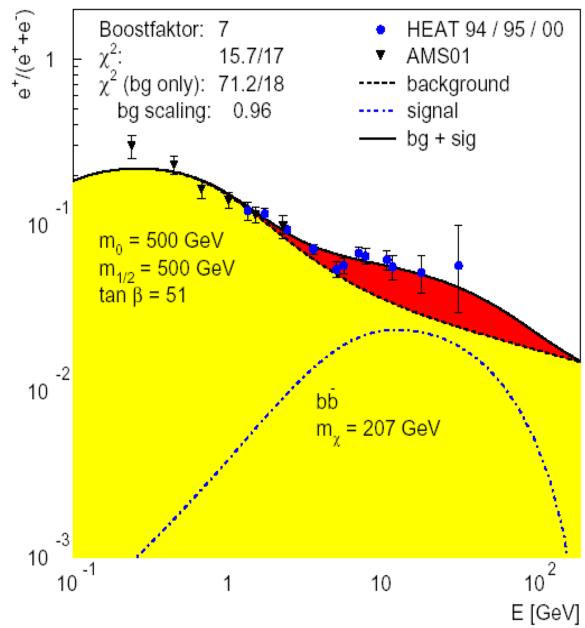
Gamma, galactic centre



Antiproton flux, BESS



Positron flux, AMS, HEAT



A Global fit to galactic centre gamma-ray flux, antiproton flux and positron flux. Same Dark Matter model, same background model. W. De Boer et al., Eur. Phys. J. C33(2004)S981.

Neutralino mass 207 GeV.

Conclusions

- Measurements of extra-terrestrial antimatter has evolved considerably since the discovery of the antiproton in 1955
- The new satellite experiments PAMELA and AMS have unique possibilities to search for signatures from *neutralino and Kaluza-Klein dark matter particles* in spectra of antiprotons and positrons as well as a more sensitive search for antinuclei.

Thanks

to

- The organizers for a stimulating symposium
- Colleagues in the CAPRICE and PAMELA experiments